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Zak, W.M.; Walmod-Larsen, Niels Ole

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Experimental Investigations of the Release of Radioactivity under Accidental Conditions in a Reactor Containment Building

by

W. M. Zak *

and

O. Walmod-Larsen

Danish Atomic Energy Commission
Research Establishment Risö
Health Physics Department

Abstract

Experimental measurements of the dynamic as well as the static spread pattern of large amounts of airborne radioactivity suddenly released in the DR 3-reactor shell at Risö were made by means of releases of ^{41}Ar. A method of data treatment was worked out by which the data from the different measurement points and releases could be standardized and therefore directly compared. An evaluation of the preferred ventilation conditions and evacuation routes in the case of a sudden release of activity was made. Only one or two minutes elapse before significant increases in the activity concentrations are observed in and around the crane well. The control room, the elevator stairs and the personnel air lock are not affected until after several minutes. Recommendations on the present system are given.

*) Permanent address: Institute of Nuclear Research, Swierk - Otwock, Poland.

Contents

Introduction

The experiments described in this report were undertaken with a view to investigating the behaviour of airborne radioactivity released under accidental conditions in a reactor containment building. The release experiments were made in the DR 3 shell at Risö. DR 3 is a 10 MW (thermal), heavy-water-cooled and -moderated research reactor of the Pluto-type. Its main purposes are material testings, neutron physics experiments and isotope production.

The reactor building is a cylindrical steel structure, 21 m in diameter and 22 m high. The reactor is centrally placed and is served from a number of galleries which in some places tend to restrict the free circulation of air, see figs. 1 to 4.

A balanced ventilation system is installed which provides an air flow of approx. 8000 m^3/h through the reactor shell under normal conditions. In the outlet the air passes through the internal storage block for spent fuel elements and gives the cooling necessary to remove the fission product heat in the elements. It then passes one of two filter banks and is finally let out into the atmosphere through a stack the height of which is approx. 22.5 metres.

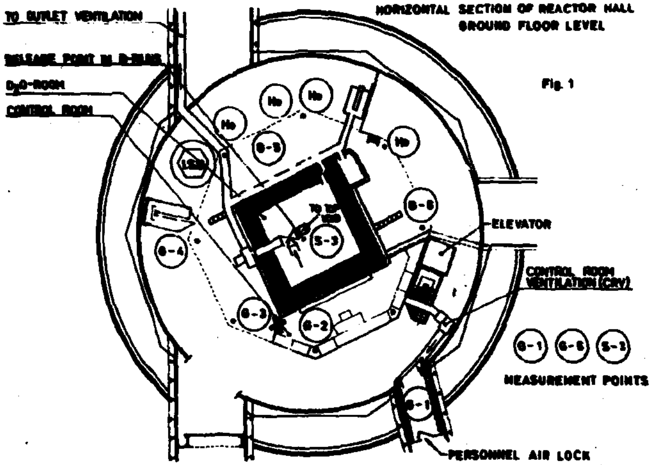
In each of the filter banks (see fig. 5) a set of three gamma monitors (gamma-air-duct monitors) is positioned between the pre-filters and the absolute filters. In a two out of three system they are connected to the automatical reactor safety system. If an exposure level of 100 mR/h (the present level) is measured on two of these monitors, the emergency trip function in the reactor safety system is automatically activated. It includes reactor trip and establishment of building seal conditions in the reactor shell. Two valves positioned in the ventilation inlet and outlet are closed, and the fans in the intake and in the outlet before the stack are stopped.

Three air locks allow access through the shell. Two are on the ground floor, one for vehicles and one for ordinary personnel use, and one is on the first floor for emergency use. Only the personnel and vehicle air locks are used under normal conditions. Use of the emergency air lock is forbidden except under incident conditions.

In addition to the normal ventilation system, nine aerotherm circulators are mounted on the shell wall above the crane balcony. Their main purpose is to remove excess heat and thus ensure comfortable working conditions within the shell.

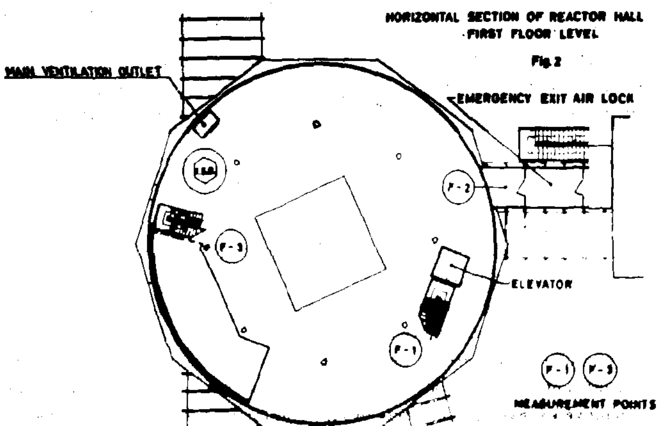
HORIZONTAL SECTION OF REACTOR HALL
GROUND FLOOR LEVEL

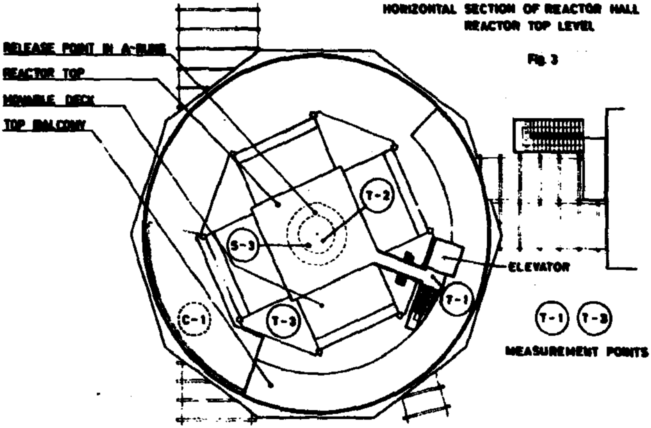
Fig. 1



HORIZONTAL SECTION OF REACTOR HALL
FIRST FLOOR LEVEL

Fig. 2

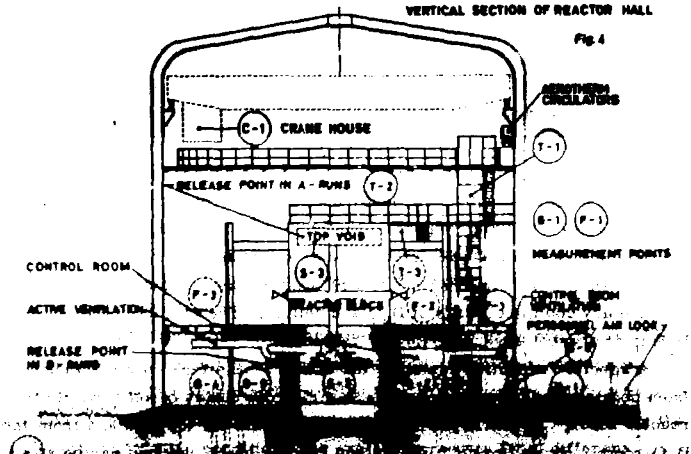




HORIZONTAL SECTION OF REACTOR HALL
REACTOR TOP LEVEL

Fig. 3

(C-1) APPROXIMATE PLACE OF MEASUREMENT POINT (SEE VERTICAL SECTION OF REACTOR HALL)



VERTICAL SECTION OF REACTOR HALL

Fig. 4

(-) APPROXIMATE PLACE OF [illegible] SECTION OF REACTOR HALL)

HORIZONTAL SECTION OF VENTILATION BUILDING
GROUND FLOOR LEVEL

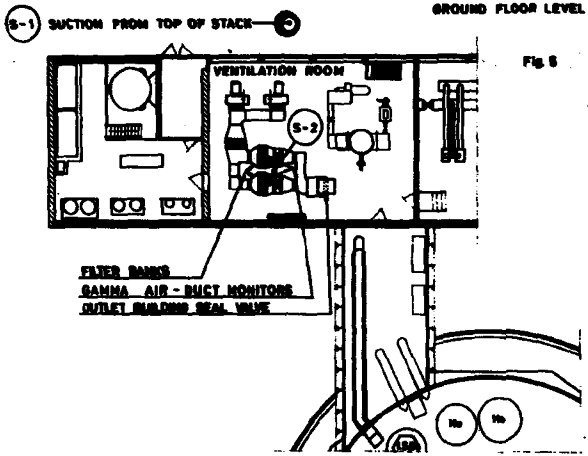


Fig 6

By means of a blower behind the control room a cooling air stream through the control room electronics panels is let out in the ground floor area and in the inner part of the personnel air lock (see fig. 1). In the latter case the air stream is to prevent condensation of water vapour on the walls in cold periods.

The main risk points of accidental release of radioactivity are considered to be the top void and the D_2O-room.

The top void is below the reactor top plate and above the reactor top shield and has a volume of approx. 3 m^3 (3.3 m$^{\phi}$, 0.5 m high). Here all fuel elements and irradiation experiments are connected.

The D_2O-room (about 55 m^3 of air) is below the reactor and contains the primary cooling circuits of D_2O and helium. The tritium content in the D_2O is at present several C/l.

A special ventilation system, "the active ventilation", provides suction from points or volumes where there is a risk of release of activity. In the reactor block, suction is provided especially from the top void and from the D_2O-room. From two ring lines in the reactor block, suction can be effected from each face of the reactor at first floor level and at top level.

For improved suction from the D_2O-room, if necessary, the reactor block system is provided with a valve permitting suction either mainly from the D_2O-room or from the top void plus ring lines. The valve is in the D_2O-room at the point where the channel leaves the reactor block.

Just outside the D_2O-room a booster fan compensates for the higher flow resistance in the smaller ducts in the block system.

As can be seen in fig. 1, a channel connected to the system after the booster fan provides suction from the D_2O-room, from the different He-cleaning systems and from the main area near the He-containers.

After the main ventilation stream from the reactor hall has passed the internal storage block for fuel elements, it meets the active ventilation outlet before passing the reactor shell, the outlet building seal valve and the filter banks.

In case of building seal conditions, which can also be established manually from the control room, the booster fan is automatically stopped, while the aerotherm circulators and the control room ventilation are not affected.

A sudden release of a large amount of airborne activity to the top void or to the D_2O-system might activate the building seal function. Great concentrations of activity are then present in the filter banks, round the closed building seal valve in the ventilation channel and backwards in the active ventilation outlet, in the active ventilation system, and at the place of release.

As the part of the system placed in the reactor hall is not tight, the spread pattern of activity in the reactor shell from this system is complex.

The small underpressure normally maintained in the active ventilation system is very quickly relieved, and the activity spreads through ducts and the different openings in the systems. The control room ventilation and the aerotherm circulators, which are kept running, have a stirring effect and might have an influence on the spread pattern. A vertical movement of air may also take place in the openings - the crane well - which through the top level and the first floor give access for the crane to the ground floor area near the vehicle air lock.

This report describes an experimental approach to an evaluation of the spread pattern of large amounts of gaseous activity released suddenly to the top void and the D_2O-room and resulting in activation of the building seal function. The experiments have been concentrated especially on finding the preferable ventilation conditions and evacuation routes from different working places in the reactor hall.

As tracer isotope was chosen the inert noble gas ^{41}argon, which was released in the milli- and in the curie-ranges in a series of experiments. From a health physicist's point of view, ^{41}Ar is well suited as it is only considered an external radiation source.

The spread pattern was measured by means of the permanently installed radiation and air contamination monitors as well as some monitors specially arranged for that purpose at a number of measurement points.

Before the experiments were carried out, the monitors were calibrated against known amounts of ^{41}Ar. The calibration procedures and the monitor responses are shown later and are described in detail in ref. 1.

In the choice of measurement points in the reactor shell the possible evacuation routes in case of emergency, namely the doors from the control room, the air locks, the different stairs, and the gangway on the reactor top, were taken into consideration. The following measurement points were chosen:

On the ground floor (see figs. 1 and 4):

G-1 in the personnel air lock
G-2 in the control room
G-3 outside the control room door facing the crane well
G-4 near the stairs to the first floor
G-5 near the helium containers
G-6 outside the control room door near the elevator

On the first floor (see figs. 2 and 4):

F-1 near the elevator stairs
F-2 in the emergency air lock entrance
F-3 near the stairs to the ground floor from the internal storage block.

At the reactor top level (see figs. 3 and 4):

T-1 at the gangway near the elevator stairs
T-2 at the reactor top plate
T-3 at the movable deck (1 m below reactor top level) near the crane well
C-1 at the crane balcony over the crane well.

At all the measurement points mentioned the suction inlet was placed in normal breathing height, 150 cm above floor level.

In fig. 5 the following measurement points can be seen:

S-1 one metre above the stack outlet

S-2, the gamma-air-duct monitors.

Release Method

For production of the necessary amount of ^{41}Ar for the experiments a low-flux irradiation tube - type 4VGR with an effective volume of 15 litres and an average flux density of 10^{12} nv - was made available at the reactor top.

The set-up used for production and release of ^{41}Ar is shown in fig. 6.

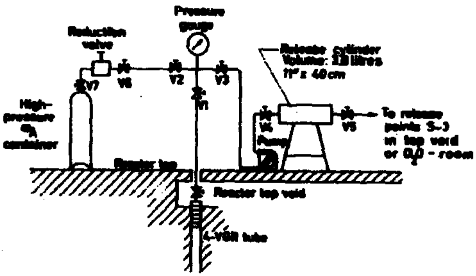


Fig 6. Set-up used for production and release of ^{41}A during A- and B-runs.

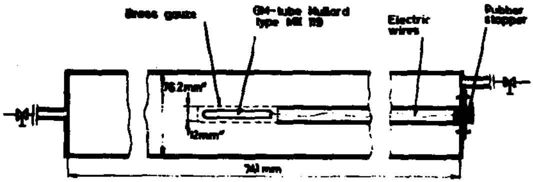
Prior to a release the activity to be used was transferred from the 4-VGR-tube to the release cylinder, where an activity estimation took place on the basis of measurements of the gamma exposure rates at well-defined distances from the cylinder centre.

The exposure rate at a distance of one metre from a ^{41}Ar point source of 0.66 rhm/C was used in the estimations.

The best way of getting as sudden a release as possible was found to be the following: After depositing of the activity in the release cylinder, the suction side of the pump was [illegible] to open air. When V4 was opened, the running pump raised the pressure in the cylinder to about 1.5 ata, whereupon V5 was opened as quickly as possible. Normally the transfer of the activity to the release volume in question was completed within a few seconds.

Measurement Method

For control of the activity concentration in the release volumes vs. time during the different releases a flow chamber, shown in fig. 7, was used. This control point, called S-3, is seen in figs. 1, 3 and 4.

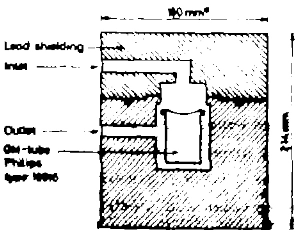


Flow chamber for control of the activity concentration at the release points (S-3). GM-tube connected to a D.C. amplifier NE-177A.

Fig. 7

As measuring instruments in the experiments the health physics instruments normally available in the reactor hall were primarily used. Three tritium monitors of Risö design were placed at the measurement points G-3, G-6 and T-3. Further three continuous air monitors, two of the Risö type positioned at G-4 and G-5, and one of Tracerlab. design at C-1, were used. These and an iodine monitor at T-1 all had their own recorders.

In addition seven flow houses were placed at the measurement positions G-1, G-2, F-1, F-2, F-3, T-2, and S-1. The design of the flow houses is shown in principle in fig. 8 and is further described in ref. 2. Each flow house is provided with a Geiger tube connected to an Airmec 1021 B rate meter. The output from the six rate meters first mentioned was registered on a six-channel recorder.



6 cm lead-shielded flow house connected to Airmec 1021 B rate meter

Calculation Method

The large number of data from the experiments were registered on many types of paper from different types of recorders. As it was very complicated to compare the data, an attempt was made to find an easy method of standardization and addition of corrections for the many different circumstances affecting the measurements.

The following procedure was worked out: The data on the recorder registration paper were transferred by hand to a transparent paper of a size suitable for an automatic curve reader coupled to the Risö analogue-digital hybride computer. This machine, which had been coded for the purpose (ref. 3), transformed the curve data to digital form on punched tape, suitable for further treatment in the Risö-GIER datamat.

By means of special programmes the necessary correction factors - decay factor, standardization factor and factors referring to the individual measurement points and runs - were applied to the data:

1. Decay factor of ^{41}Ar:

$$f_d = e^{\frac{0.693 \cdot t}{T}} ,$$

where t is the time in minutes from the start of the release; T is the half-life of ^{41}Ar = 110 min.

2. Factor for standardization of the activity released to one curie:

$$f_N = \frac{A}{A_o} ,$$

where A_o is the actual amount of released activity in C; A is the standardized activity = 1.0 C.

3. Monitor sensitivity factors as described below and in ref. 1.

4. Shield factors applied to background-sensitive monitors:

$$f_s = \frac{\text{monitor response [illegible] detection volume}}{\text{monitor response [illegible]}}$$

Details are given below.

5. Axis scale factors.

After the necessary data treatment it was possible from the GIER-plotter to obtain final standardized and directly comparable curves from the individual measurement points and runs as desired.

Because of the many different sensitivities of the monitors - some had linear and some nonlinear response - the accuracy of the final standardized curves is estimated to be approx. 10% for the linear systems and approx. 20% for the nonlinear systems used at the measurement points G-4, G-5, S-2, and S-3.

Monitor Sensitivity Factors

The different monitor types used in the experiments were all calibrated against ^{41}Ar by exposure to known concentrations of activity in the set-up shown in fig. 9.

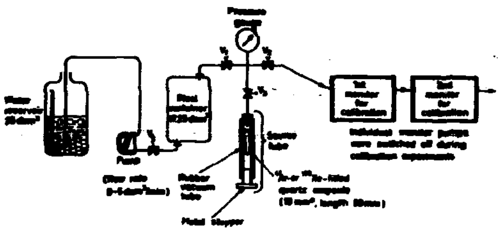


Fig. 9. Set-up for calibration of monitors.

The ^{41}Ar activity, delivered in a quartz ampoule, was placed in a vacuum rubber tube, which was closed by means of a metal stopper. Vacuum was then applied to the steel container. After crashing of the ampoule the activity was transferred to the steel container by opening of V1 and V3 and by letting in of air at the stopper-end of the rubber tube until the pressure difference was eliminated. This way of transferring the ^{41}Ar activity left less than one per cent outside the steel container.

The air in the steel container, of a known concentration of activity, was then applied to the monitors to be calibrated in a slow, constant stream obtained by pumping a constant flow of water on to the bottom of the steel container. The flow through the monitors was maintained for approx. ten minutes so that a uniform distribution of activity *inside* the detection volume was reached. For the same reason and for elimination of the differences in flow rates the individual monitor pumps were switched off during the runs.

The response curves, giving a correlation between the monitor response and the concentration of ^{41}Ar-activity, are shown in figs. 10 to 13. Fig. 10 is for the Risö tritium monitor, fig. 11 for the Tracerlab. continuous monitor for airborne particulate radioactivity MAP-1, fig. 12 for the Airmec 1021B connected to the GM-tube Philips type 18516 in the lead-shielded flow house, and finally fig. 13 is for the Risö continuous air monitor.

The flow chamber (fig. 7) used for measurement of the concentrations at the release points was calibrated in the *following* way: The activity from the quartz ampoule was applied *directly to* the chamber in the same way as to the steel container (*fig.* 9). Two instruments, a DC-amplifier NE-177A and the fission gas station monitor, both measuring the current from the GM-tube in the same ranges, were connected to the flow chamber as shown in fig. 14, which also shows the curve giving the correlation between the response of the monitors and the concentration of ^{41}Ar.

The calibration accuracy is estimated to be approx. 10%.

Further details of the calibrations are given in ref. 1.

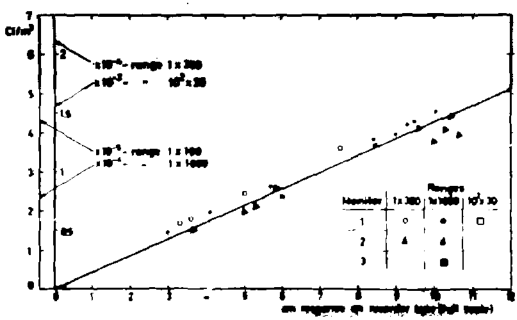


Fig. [illegible]

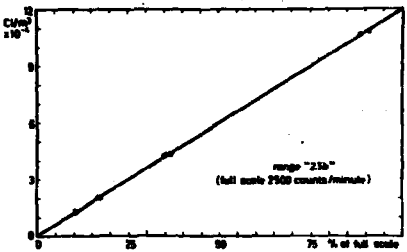


Fig. 11 ^{41}Ar response curve of Tracerlab continuous monitor for airborne particulate radioactivity, MAP - 1.

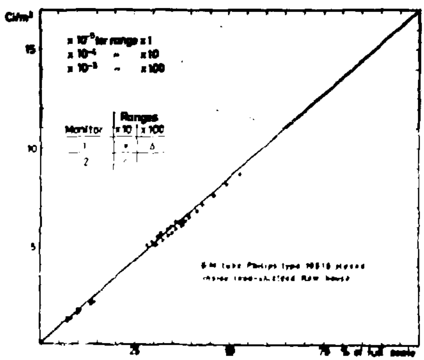


Fig. 12. ^{41}Ar response curve of Aktinix 1921 B monitor

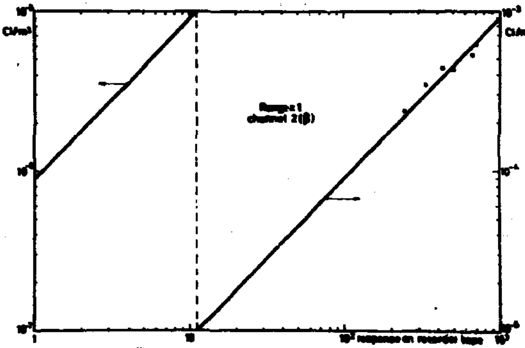


Fig. 13. ⁴¹Ar response curve of Risø continuous air monitor.

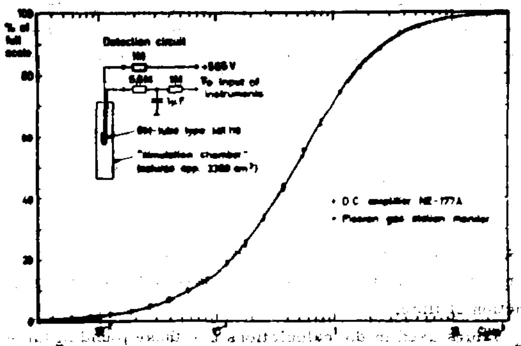


Fig. 14. ⁴¹Ar response curve of GM-tube in "flow chamber".

Shield Factors

The data necessary for calculation of the shield factors for the different monitors were obtained during two similar runs with releases of activity to the top void, run A-2a (without flow through the detection volumes) and run A-2b (monitors in normal flow conditions). Prior to the releases building seal conditions (BS) were established.

Further data of the runs are shown in table 1.

Table 1

Data of the runs A-2a, A-2b, A-2, A-3, B-2, and B-3

Runs	Before release: Ventilation conditions		Release of activity in C	After release: Time until changes in the ventilation conditions after start of release in minutes and seconds	
	BS	Control room vent. + aero-term off		BS reset	Back to normal cond.
A-2a	+		0.33	42 m 45 s	42.45
A-2b	+		0.335	43 m 05 s	43.05
A-2	+		0.209	79 m 52 s	79.52
A-3	+	+	0.210	78 m 55 s	
B-2	+		0.20	80 m 52 s	80.52
B-3	+	+	0.210	78 m 00 s	78.00

Curves of the monitor response in the measurement points vs. time are given in Appendix I. From these it is possible to get exact values of f_s as a function of time.

The f_s values used in the calculations are those found in table 2, which are average values for the period from 10 to 30 min after the start of release (before reset of BS).

Table 2

Shield factors used in the calculations for background-sensitive monitors

Measurement points	G						F			T			
	1	2	3	4	5	6	1	2	3	1	2	3	C
f_s	.95	0.82	1.0	.38	.33	1.0	.84	.86	.80	.6	.88	1.0	.92
Values estimated for the first 10 min x)				.26	.18					.7			

x) Only values differing more than 10% are given.

The static development of the spread pattern during the first two hours after a release was investigated in two sets of runs. In one set (A-runs) releases were made to the top void and in the second set (B-runs) to the D_2O-room. The influence of the control room ventilation (CRV) and the nine aerotherm circulators (AA) was further investigated as in the first runs (A-2 and B-2), only BS was established before the releases. In the second runs (A-3 and B-3) the CRV and AA were switched off in addition.

The data obtained are shown in detail in Appendix II, and details on the runs are given in table 1.

From the curves in Appendix II it can be seen that saturation concentrations are reached about one hour after release under BS-conditions.

In table 3 the 60-minute concentrations at the measurement points are given (point C-1 has been excluded as a too high time constant was applied to the monitor in these runs).

Table 3

Activity concentrations in mm (x $5 \cdot 10^{-6}$ $C/m^3 \cdot mm$) at the measurement points 60 minutes after start of release for runs A-2, A-3, B-2 and B-3

Measurement points	A-2	A-3	B-2	B-3
G-1	29	22	36	28
G-2	34	19	28	18
G-3	64	68	95	76
G-4	45	43	45	35
G-5	44	53	48	32
G-6	49	46	78	53
F-1	36	34	34	34
F-2	39	35	29	23
F-3	43	43	35	43
T-1	27	23	19	12
T-2	42	38	21	29
T-3	58	53	44	43

Switching off of CRV and AA has little effect except at the ground floor level during B-releases, where the saturation activity level is found to be significantly lower, probably because of the absent stirring effect of the CRV, whose outlet must cause a circulatory movement of the air round the reactor block at the ground floor level.

The highest saturation concentrations found on the curves in Appendix II are reached at C-1, crane balcony level. Table 3 shows furthermore that high values are reached at G-3 to G-6, ground floor level, at F-3 at the first floor level and finally at T-3 at the top level, most of them in or near the crane well.

The lowest concentrations are found at G-2 and G-1 in the control room and in the personnel air lock, and finally at T-1 neat the elevator stairs at the top level.

During run A-2 some additional measurements were made of the beta + gamma (b+g) and the gamma (g) exposure levels at the measurement points and inside the elevator positioned at the reactor top level. These measurements were made by means of an ionization chamber, Victoreen Survey Meter, Model 440, at a height of 100 cm above the floor level. At

C-1 the exposure levels were not measured at the suction point on the crane balcony, but three metres below it at the reactor top balcony (just next to the monitor).

The data obtained are shown together with the activity concentrations in figs. A III-1 to A III-14 in Appendix III.

From these data it is possible to find the ratios between beta + gamma or gamma exposure level and specific activity.

The resetting of BS may give rise to an increase in the radiation levels near the active ventilation ducts as higher concentrations of activity will pass through the channels from the reactor block.

(On the activity concentration curves for the points G-5 and G-4 a rise following the BS-resetting after 80 min is seen. This is due to the background sensitivity of the monitors placed at these points).

At point F-3 the concentration of activity is maintained at nearly the same level for approx. 20 min after BS-resetting. This might be caused by the passing of the main outlet stream of air from the reactor hall into the main suction point in the neighbourhood of the F-3 monitor.

Measurements on the Release Dynamics

In order to find the safest evacuation routes under the various conditions of the ventilation system considered - whether of the CRV and the AA should be switched off in case of BS or not, and whether the suction in the active ventilation system should be mainly from the top void, from the D_2O-room or in between - we made three further series of runs. We tried to keep the conditions during the releases as close as possible to normal working conditions for the ventilation system. BS was established manually from the control room when a level of approx. 10 mR/h was reached on the gamma-air-duct monitors (1/10 BS limit of 100 mR/h). In one of the runs BS was established at 1/20 BS limit (B-4d).

One way of analysing the data in order to get detailed information about the conditions after an activity release is to look at the delay times before the activity is registered at the different measurement points.

Detailed data of the runs are given in table 4. The curves showing the activity concentration vs. time at the different measurement points are to be found in Appendix IV.

In order to work with a well-defined value we decided to measure the delay time before a level of 10^{-5} (C/m^3 per curie released) of the released activity was reached at the measurement points. The values measured in minutes are given in table 5.

By comparison of the delay times found for the A-4 runs c, e and f it can be seen that the c-conditions - BS and at the same time CRV + AA switched off - generally give the significantly longest delays, as is also indicated in the data in Appendix II.

Table 4

Data of the series of runs A-4, B-4 and B-4d

Runs	Before release Active vent. mainly from		Release of activity in C	After release Time until changes in the ventilation conditions after start of release in minutes and seconds				
	top void	D_2O-room		BS	Control room vent. off	Aerotherm app. off	Back to cond. before release	Back to normal cond.
A-4a	+		7.87	00.56			06.41	06.41
A-4c	+		0.64	00.59	00.59	00.59	24.51	24.51
A-4d		+	0.87	01.59			24.42	148.34
A-4e	+		0.734	00.52			24.44	24.44
A-4f	+		0.695	01.00	01.00		24.47	24.47
B-4a	+		1.36					
B-4c	+		1.5	01.20	01.20	01.20	11.46	11.46
B-4e	+		2.73	02.10			10.22	10.22
B-4f	+		1.75	02.09	02.09		12.23	12.23
B-4d-a		+	7.13					
B-4d-c		+	2.46	00.53	00.53	00.53	11.00	11.00
B-4d-e		+	2.45	00.52			10.52	10.52
B-4d-f		+	2.55	00.56	00.56		11.13	11.13

Table 5

The delay in minutes before a 10^{-5} level (x C/m^3 per curie released) is reached at the measurement points after start of release

Runs	A-4 release to top void				B-4 release to D_2O-room				B-4d			
	c	d	e	f	a	c	e	f	a	c	e	f
					Active vent. mainly from top void				Active vent. mainly from D_2-room			
Conditions / Points	BS, aerotherm app. off, control room vent. off	BS, active vent. mainly from D_2O-room	BS	BS, control room vent. off	Normal ventilation	BS, control room vent. off, aerotherm app. off	BS	BS, control room vent. off	Normal ventilation	BS, control room vent. off, aerotherm app. off	BS	BS, control room vent. off
G-1	18.5	11.5	8	10.5	14	5.5	8	5.5	-	9.5	7.5	9
2	13.5	9	6.5	10.5	8	6.5	5.5	7.5	-	11	6	13
3	11	6	3.5	4	6.2	4	5	6.2	-	5.3	5.3	8.5
4	2	3	1.5	2.3	5.5	3	3	3	-	2	3	8
5	2	4	2	2	2.5	3	2.5	2.5	4	2.3	1.2	1.2
6	10	14	15	10	6	8	5.5	9	-	11	6.5	9.5
F-1	8	6.3	5	5	12	5	6	11	-	13.5	6	10
F-2	2.5	5	2.5	2.5	5	7	7	5	-	5	5	8
F-3	2.7	3.2	2	1.6	4.5	2.5	5	3.5	-	2	1	7
T-1	8	7.5	5	6	28	10.5	13	8.5	-	9	10	8
2	2	2.3	3	4.3	4.5	3	2.5	3	-	3	1.5	3
3	9	2	1	1	7	5.5	5.5	3	-	5	2.5	2.5
C	7	3	2	3	11	4	9.3	5.6	-	3.2	2.8	2.8

For testing of the emergency trip function in the automatical reactor safety system, which can be tripped by the gamma-air-duct monitors, a further run was made (A-4a) with a release of large activity amounts to the top void in connection with a scheduled shut-down of the reactor. It proved difficult to produce a sufficiently large amount of activity and get it released quickly enough to obtain the concentration in the ventilation duct necessary to give an exposure level on the gamma-air-duct monitors of 100 mR/h (several attempts were made before we succeeded). BS was activated by as fast a release as possible to the top void of approx. 8 C of ^{41}Ar.

From the B-series - a release into the D_2O-room - it can be seen that the c-condition is acceptable althouth it does not give the longest delays.

From the B-runs under a-conditions - normal ventilation - it can be seen that active ventilation suction mainly from the D_2O-room removes the activity most effectively, as was to be expected. Since suction from the top void when the release takes place there is also the best, this means that suction from both volumes should be established under normal conditions. A further conclusion is that stopping of the CRV and the AA's should be incorporated in the BS-function.

Figures 15, 16 and 17 show the activity concentrations vs. time at the measuring points at ground-floor, first-floor and top, incl. the crane balcony levels during the A-4c run.

The B-4c and B-4d-c runs are shown in a similar way in figs. 18 and 19.

The longest delay times before a significant increase in the local activity concentration took place were found at the points G-2, G-1, G-6, F-1, and T-1.

If the figures, the delays given in table 5 and the saturation values in table 3 are compared, it can be concluded that evacuation routes should not pass through or be near the crane well. The stairs from first to ground floor level near F-3 and G-4 should thus not be used. Further the control room should not be evacuated through the door near G-3. Preferred evacuation routes are shown by arrows in fig. 20.

As the zero-time in the curves is the starting time of releases, the BS-function times of approx. one minute (table 4) must be subtracted before we can obtain an idea of the reaction time left for the control room personnel from the time the BS is activated by high concentrations in the channels surrounding the gamma-air-duct monitors until significant levels are reached at the various measurement points in the reactor hall. As in some places this is a question of only a few minutes, either standing orders for the con-

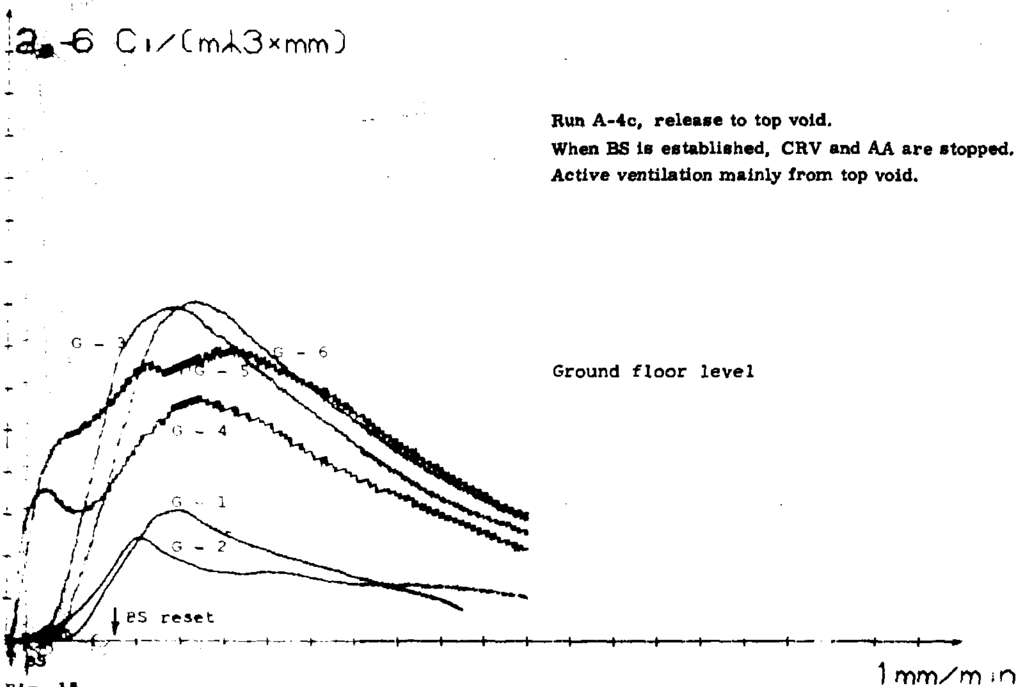

2.-6 Ci/(m⅄3×mm)
Run A-4c, release to top void.
When BS is established, CRV and AA are stopped.
Active ventilation mainly from top void.
G - 3
G - 6
G - 5
Ground floor level
G - 4
G - 1
G - 2
BS reset
BS
1 mm/min

Fig. 15.

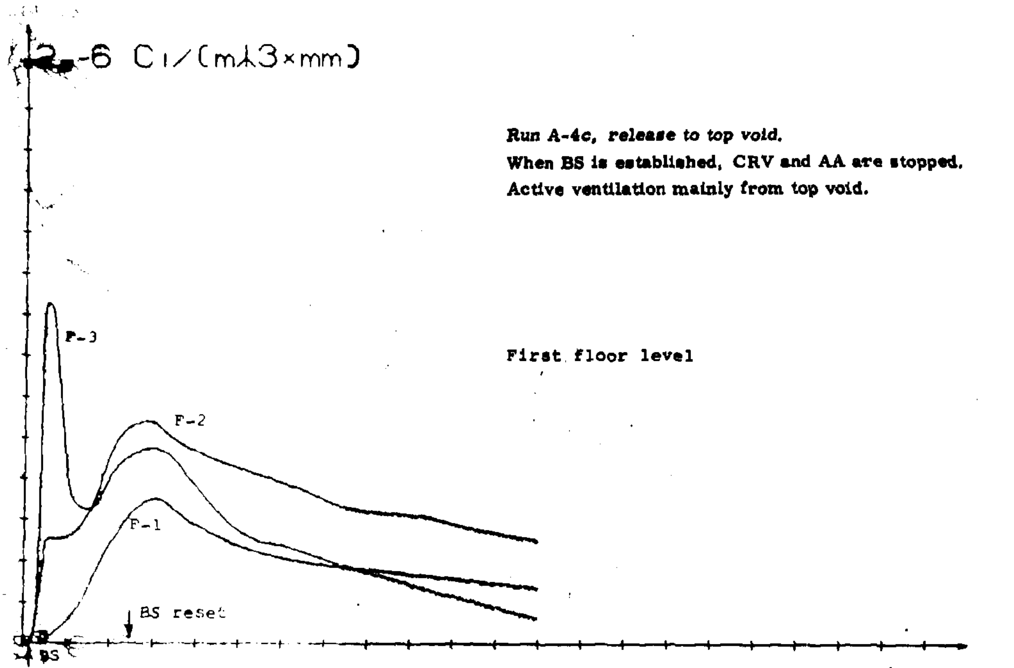

2.-6 Ci/(m⅄3×mm)
Run A-4c, release to top void.
When BS is established, CRV and AA are stopped.
Active ventilation mainly from top void.
F-3
First floor level
F-2
F-1
BS reset
BS
1mm/min

Fig. 16.

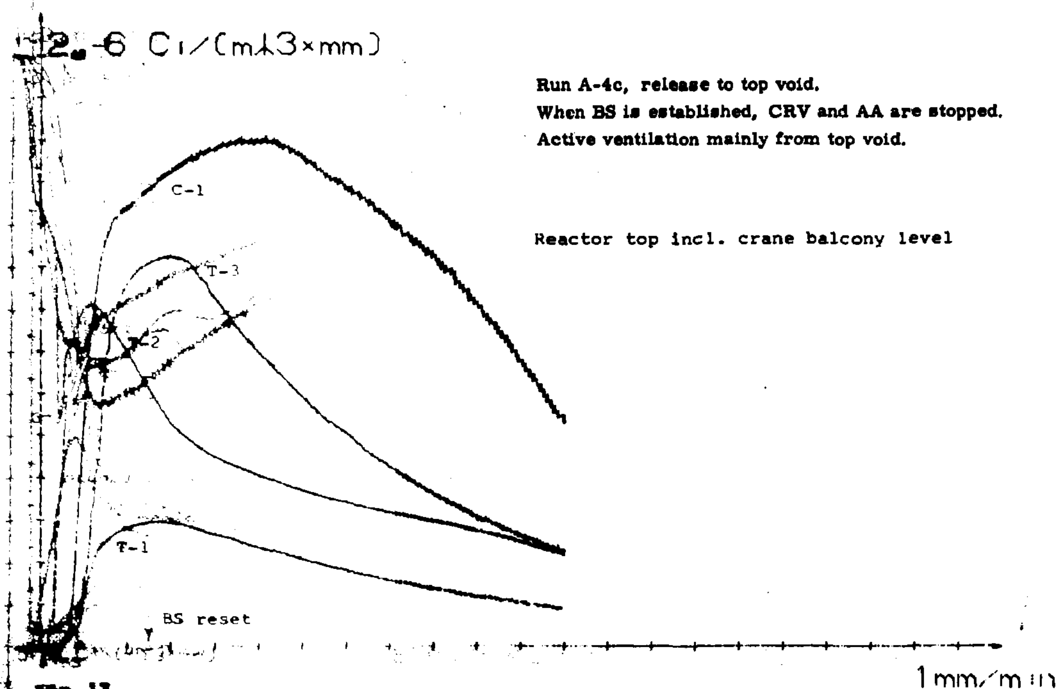

2.-6 Ci/(m⅄3×mm)
Run A-4c, release to top void.
When BS is established, CRV and AA are stopped.
Active ventilation mainly from top void.
C-1
Reactor top incl. crane balcony level
T-3
T-2
T-1
BS reset
1 mm/min

Fig. 17.

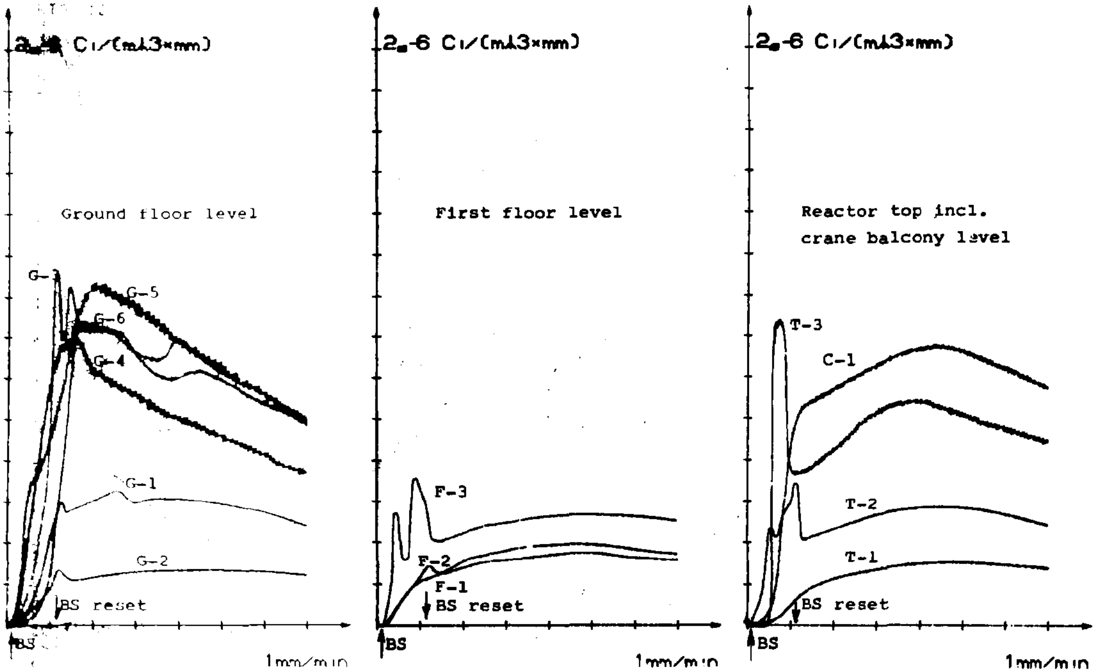


Fig. 18. Run B-4c. Release to D_2O-room. **When BS is established, CRV and AA are stopped.** Active ventilation **mainly from top void.**

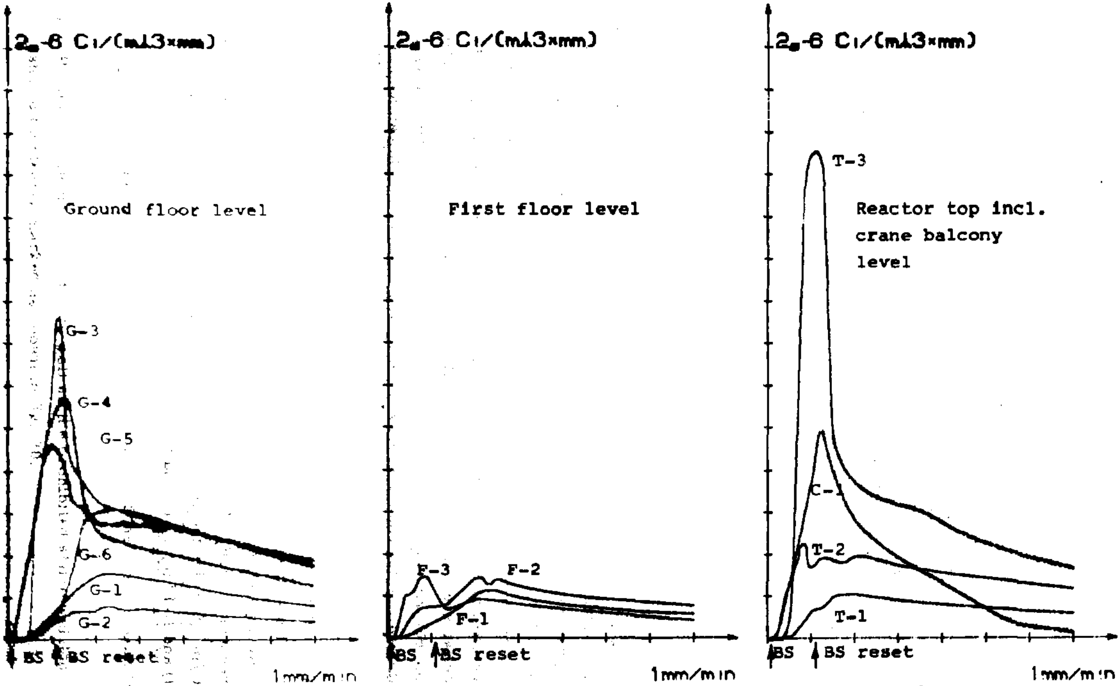


Fig. 19. Run B-4d c. Release to D_2O-room. When BS is established, CRV and AA are stopped. Active ventilation mainly from D_2O-room.

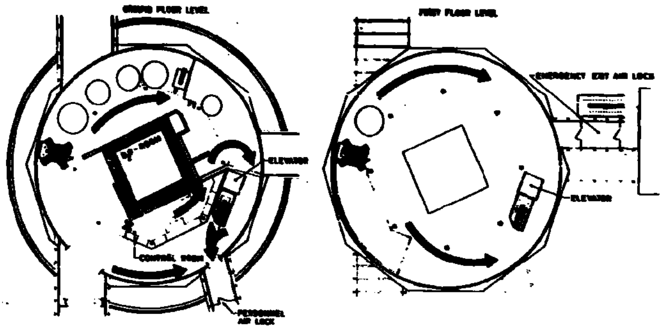


Fig. 20. Preferred evacuation routes, first floor and ground floor levels.

trol room personnel should be considered, namely that a BS activated from the gamma-air-duct monitors should immediately be followed by an evacuation signal, or the signal should be started automatically by means of direct connection between a trip on the gamma-air-duct monitors and the scram siren function.

It should be borne in mind that the present BS-limit of 100 mR/h is not reached until after a release of 5-10 C to the top void, depending on the active ventilation suction conditions. In case of release to the D_2O-room the BS-trip activity level is greatly dependent on the active ventilation conditions. In the case of suction mainly from the top void, the amount of activity that can cause a BS-trip is of the order of about 100 curies ^{41}Ar. In case of suction mainly from the D_2O-room the necessary activity amount is about 20 curies.

These conclusions are based upon the data in Appendix V giving the time dependence of stack release in C/min (S-1), gamma-air-duct monitor response in mR/h (S-2) and finally the concentration at the release point in C/m^3 (S-3) for the series of runs A-4 (a, c, d, e, and f), B-4 (a, c, e, and f) and B-4d (a, c, e, and f).

Exposures Caused by the Experiments

The total exposure to the experimenter in the fourteen weeks (15th Jan. - 12th Apr., 1969) when most of the releases were made was 870 mrems.

By comparison with the same period in 1968 during which the personnel were operating under normal exposure conditions (only the people who were working in both periods were taken into consideration) the total exposure of 2.31 man rems in the experiment period was found to be 0.32 man rem less than during the period in the year before.

Conclusion

In conclusion the following recommendations can be given on the basis of the experiments performed:

1. The control room ventilation together with the nine aerotherm circulators placed on the shell wall should be stopped automatically if the building seal function is activated from the gamma-air-duct monitors.

2. Under normal circumstances of operation the existing active ventilation system should take suction both from the D_2O-room and from the top void.

3. The scram signal should be connected to the emergency shut-down system (reactor trip, building seal, etc.) if this is activated by the gamma-air-duct monitors. Only one or two minutes elapse before significant increases in the levels of airborne activity take place in and around the crane well.

4. At the sounding of the scram siren signal, evacuation of the crane well and the neighbouring areas should start immediately. It is not necessary to run. On evacuation from the first floor the stairs from the internal storage block to the ground floor should not be used. The control room door to the crane well should not be opened. Several minutes elapse before any significant increase in the airborne activity level takes place around the elevator stairs, in the control room and in the personnel airlock. Immediate evacuation of the control room is not necessary.

5. Preferred evacuation routes as well as the prohibited stairs and door should be clearly marked as shown in fig. 20.

Acknowledgements

The authors wish to thank the DR 3-staff, the health physics staff at the DR 3 and in the Health Physics Department, and the staffs of the hybrid computer, the GIER computer and the isotope laboratory for their valuable help.

References

1) W. M. Zak and O. Walmod-Larsen, Calibration of Airborne and Gaseous Activity Monitors used in the DR-3 reactor by ^{41}Ar and ^{133}Xe. Risö-M-1215 (1970).

2) H. Flyger and H. Rosenbaum, A Monitoring Design for Radioactive Air Pollution. Risö Report No. 104 (1965).

3) K. Søe Højberg, Recorded Curve to Punched Tape Conversion with EAI 680 and PDP 8. Risö-M-879 (1969).

Appendix I

Figures AI-1 to AI-13. Specific activity vs. time after release of activity standardized to 1 C.
A-runs: release to top void.

Run A-2a - monitor response without flow through "detection volume".

Run A-2b - monitor response under normal flow conditions through "detection volume".

G-1 to G-6 - measurement points at ground floor level.

F-1 to F-3 - measurement points at first floor level.

T-1 to T-3 - measurement points at reactor top level.

C-1 - measurement point at crane balcony level.

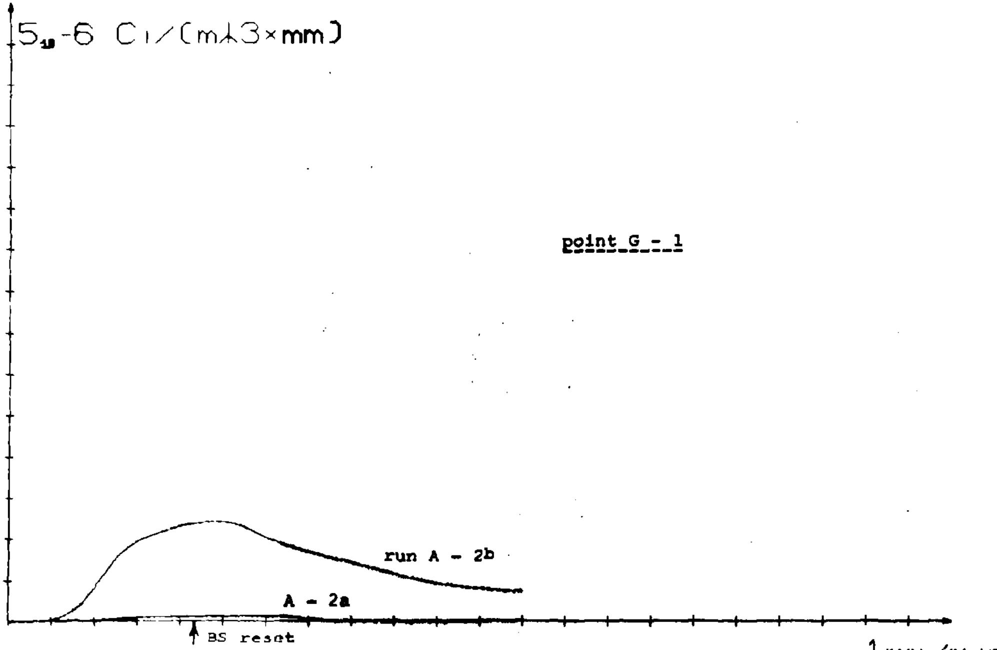


Fig. A1 - 1.

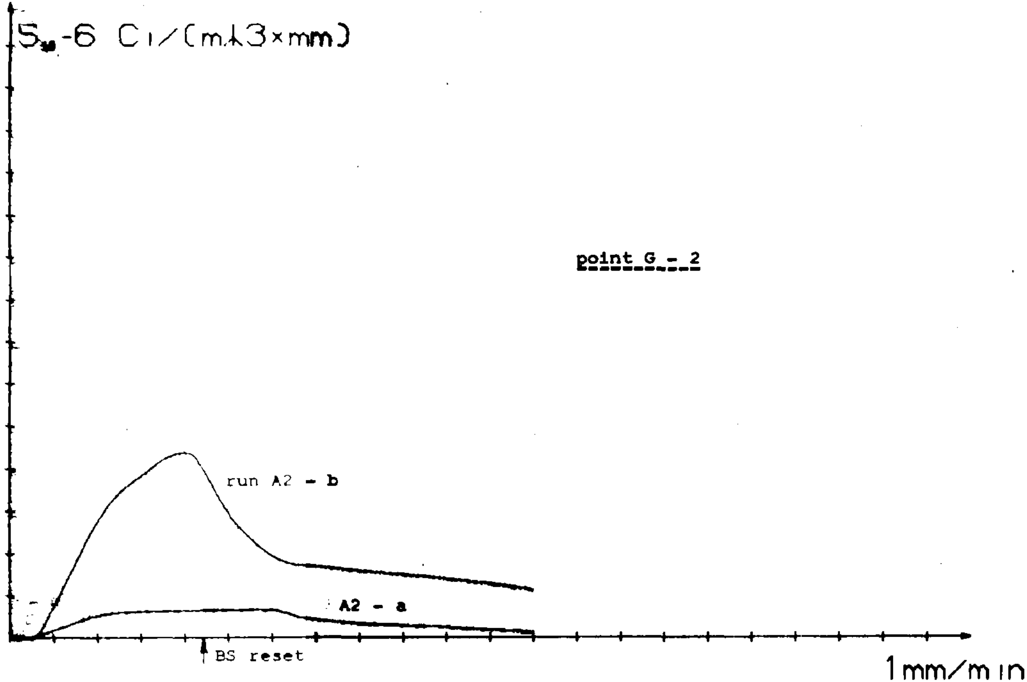


Fig. A1 - 2.

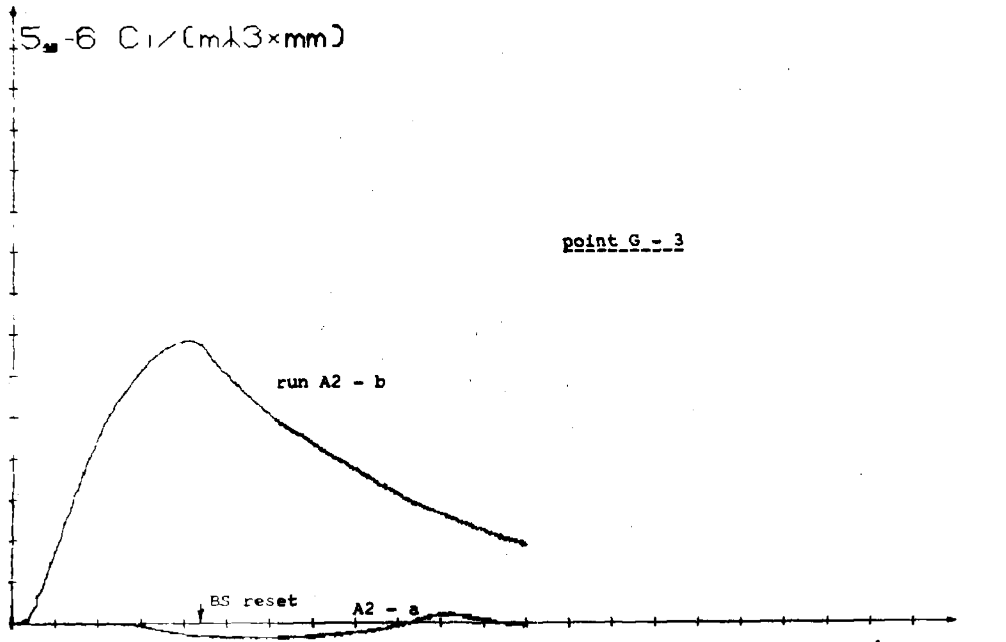


Fig. A1 - 3.

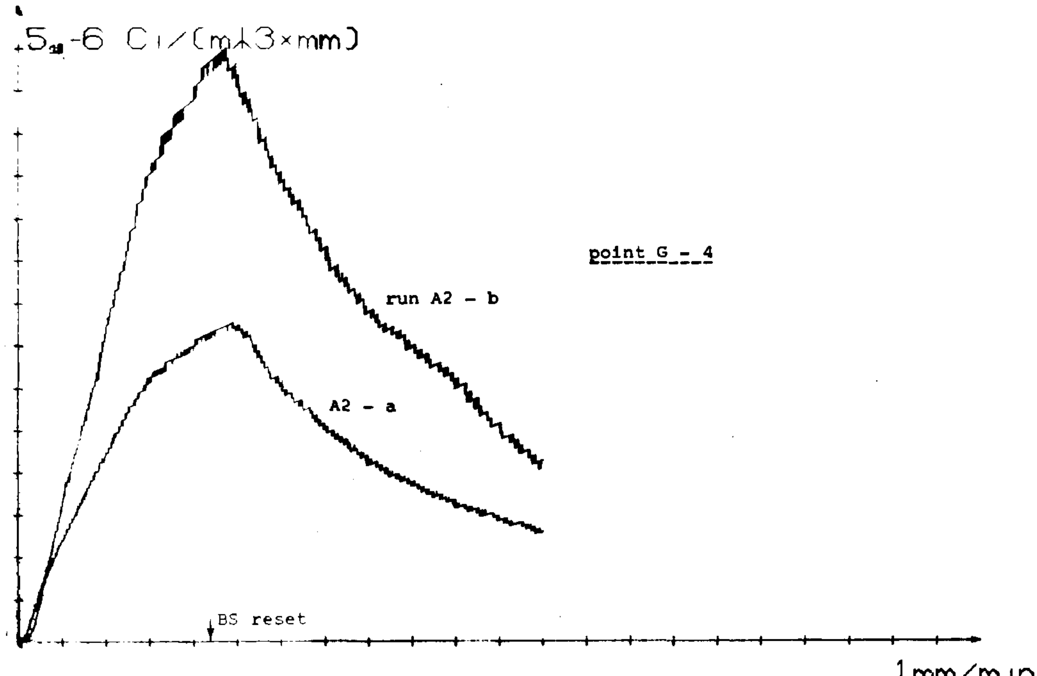
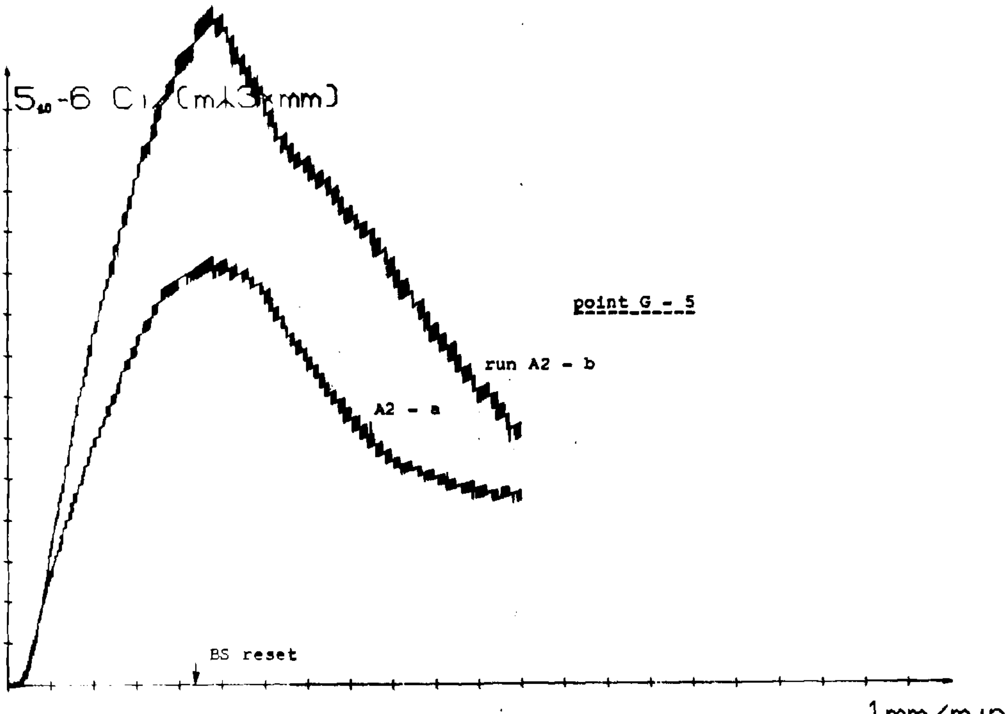


Fig. Al - 4.



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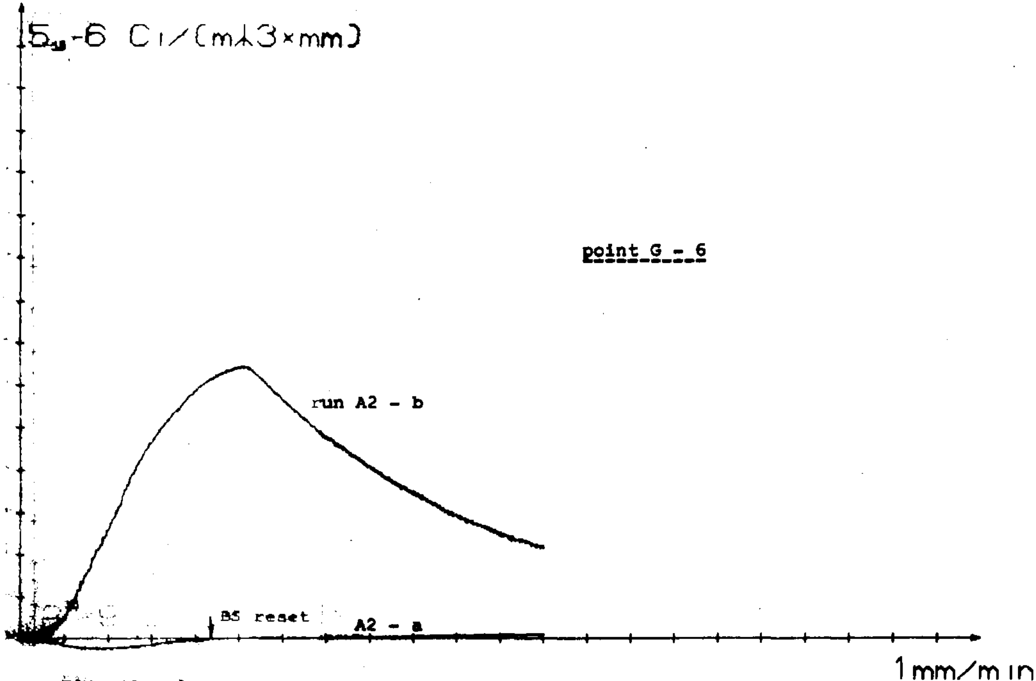


Fig. A1 - 6.

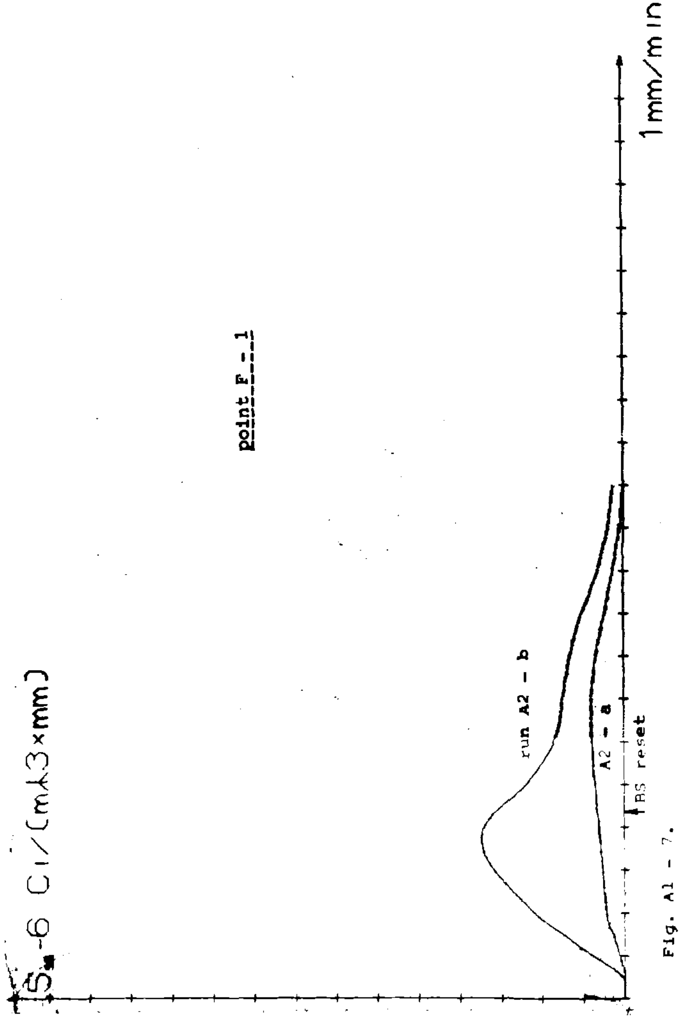


Fig. A1 - 7.

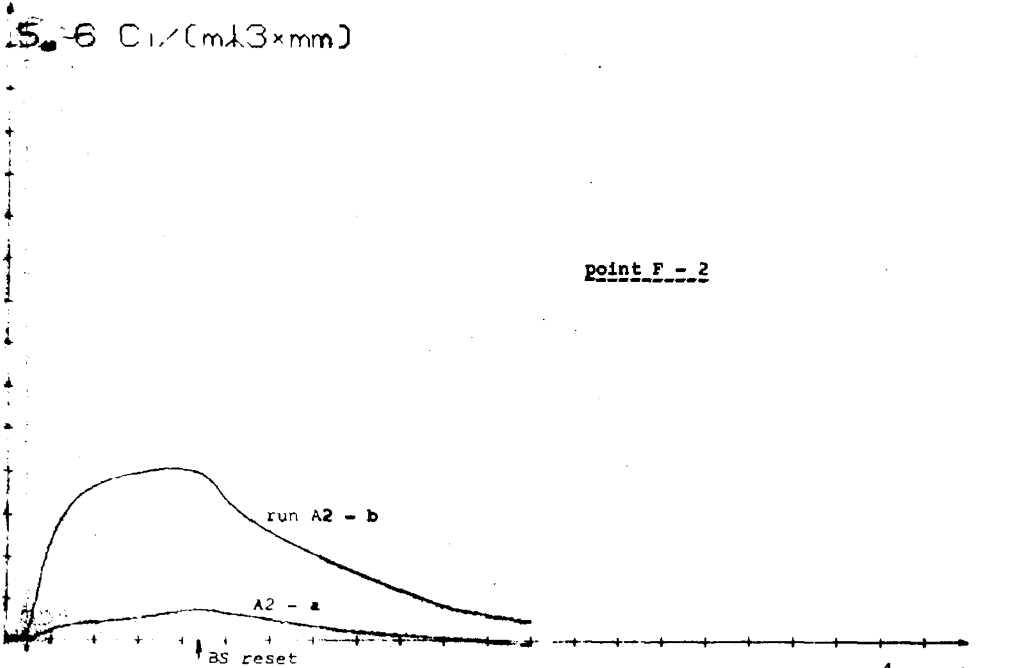


Fig. A1 - 8.

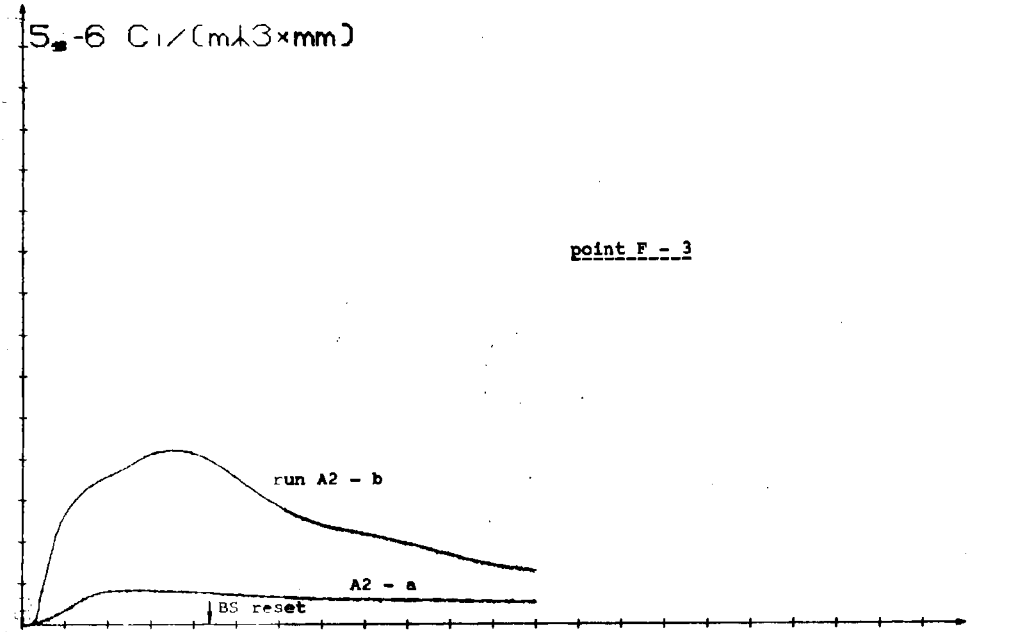


Fig. A1 - 9.

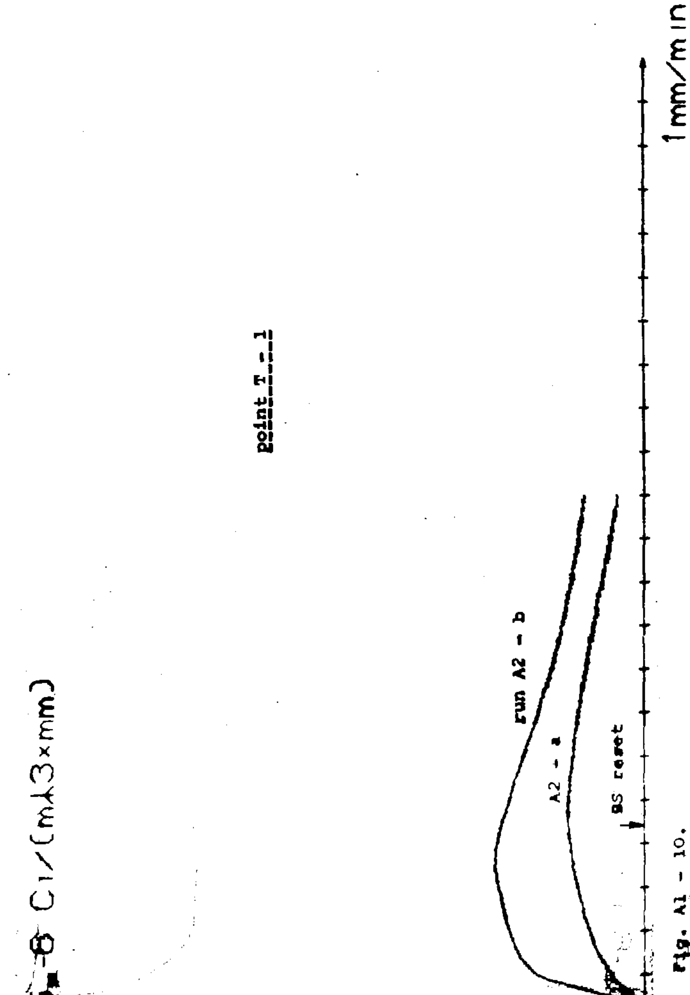
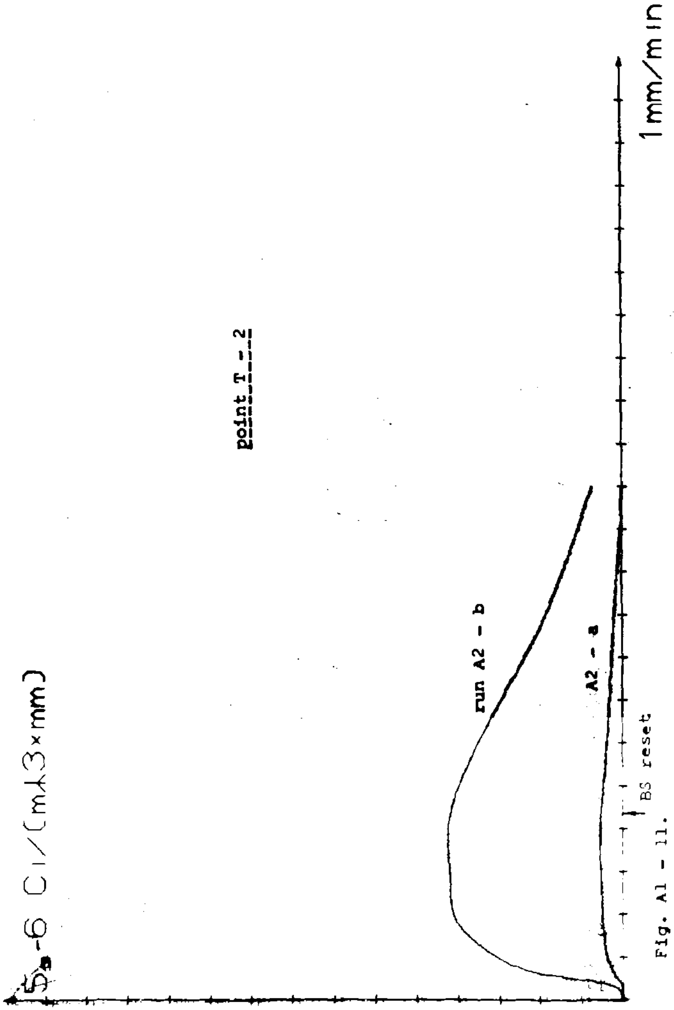


Fig. A1 - 10.



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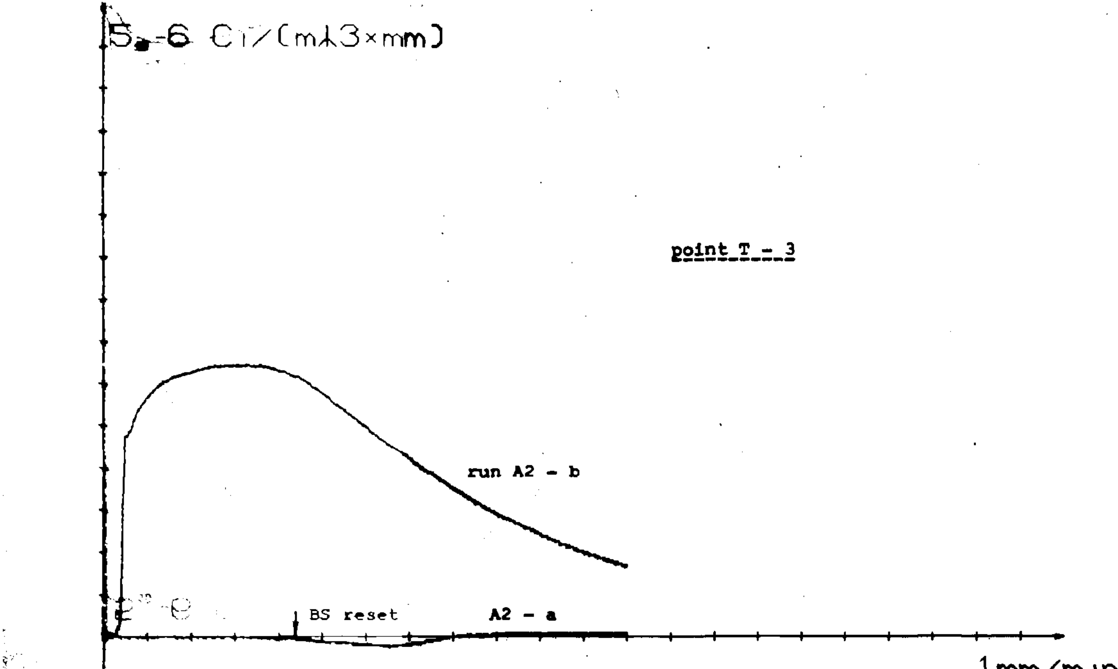


Fig. A1 - 12.

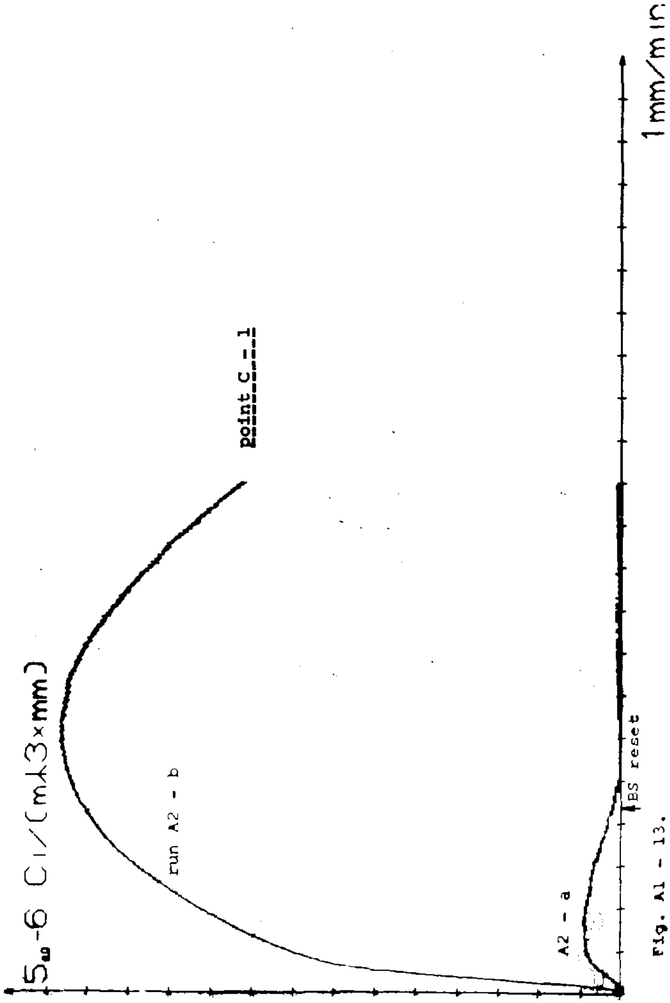


Fig. A1 - 13.

Appendix II

Figures AII-1 to AII-13. Specific activity vs. time after release of activity standardized to 1 C.
A-runs: release to top void,
B-runs: release to D_2O-room.

Run A-2 - BS before release. Control room ventilation (CRV) and aerotherm apparatuses (AA) on (normal conditions).

Run A-3 - BS before release. CRV and AA off before release.

Run B-2 - like A-2.

Run B-3 - like A-3.

G-1 to G-6 - measurement points at ground floor level.

F-1 to F-3 - measurement points at first floor level.

T-1 to T-3 - measurement points at reactor top level.

C-1 - measurement point at crane balcony level.

Note: At C-1 a too high time constant was applied to the monitor in these runs.

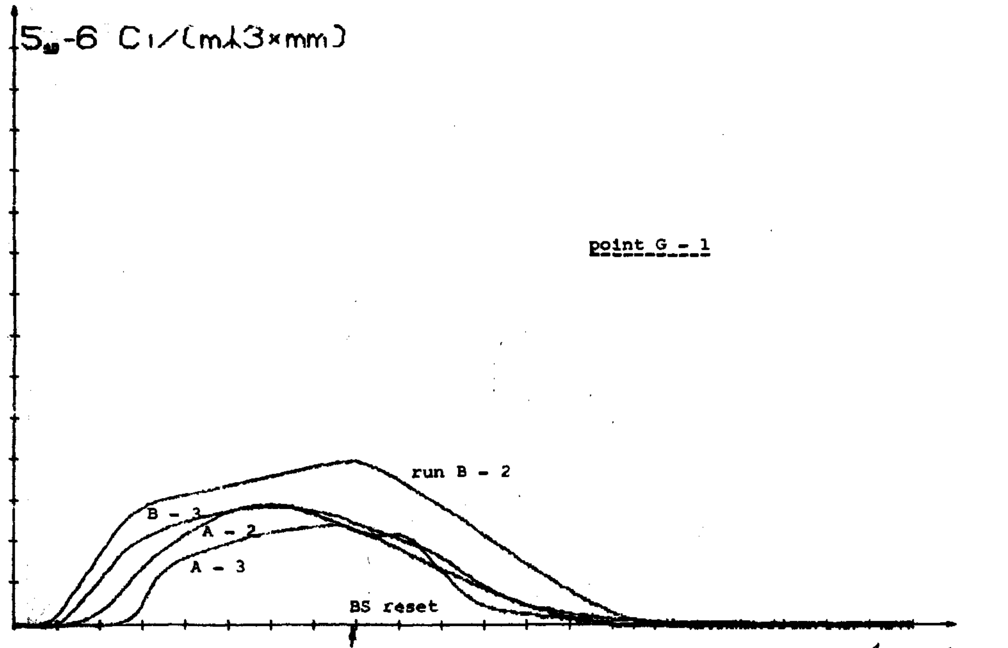


Fig. AII - 1.

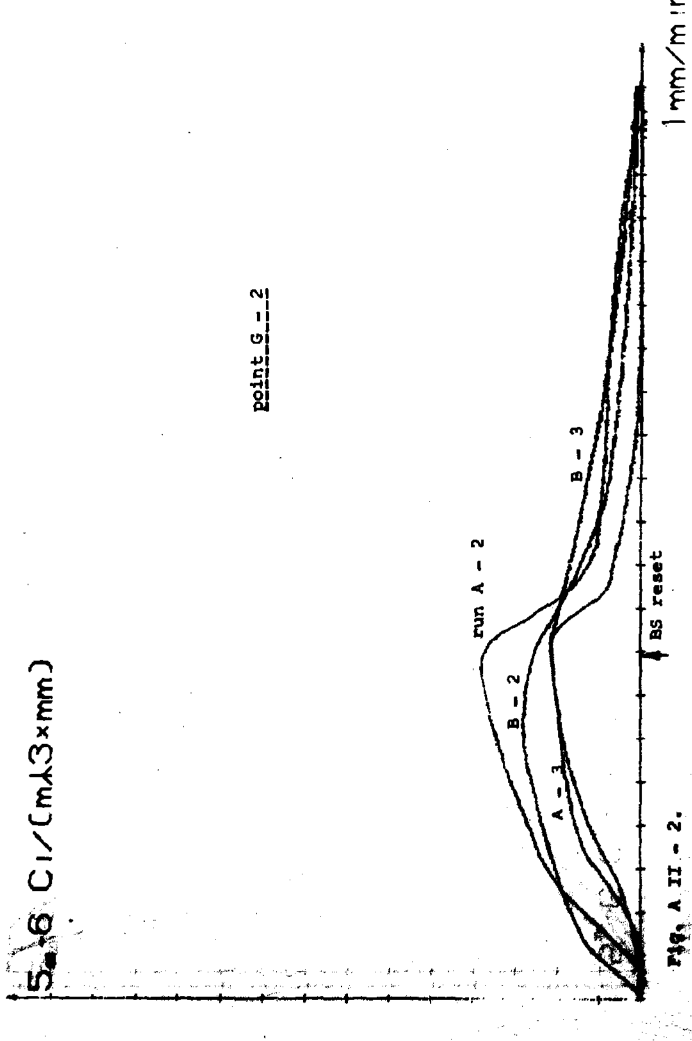
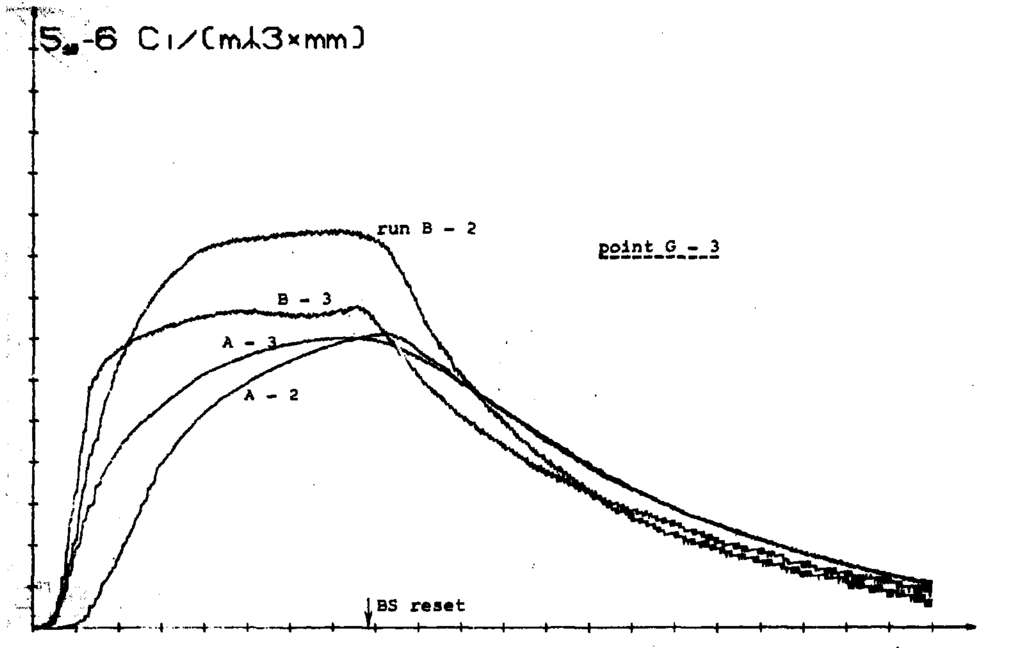


Fig. A II - 2.



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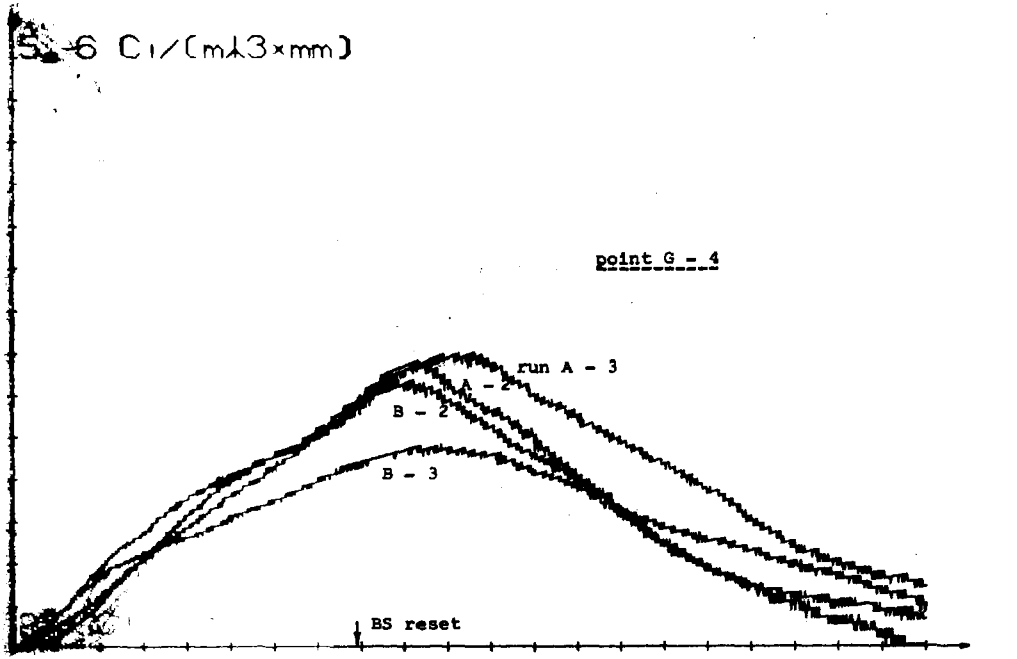


Fig. A II - 4.

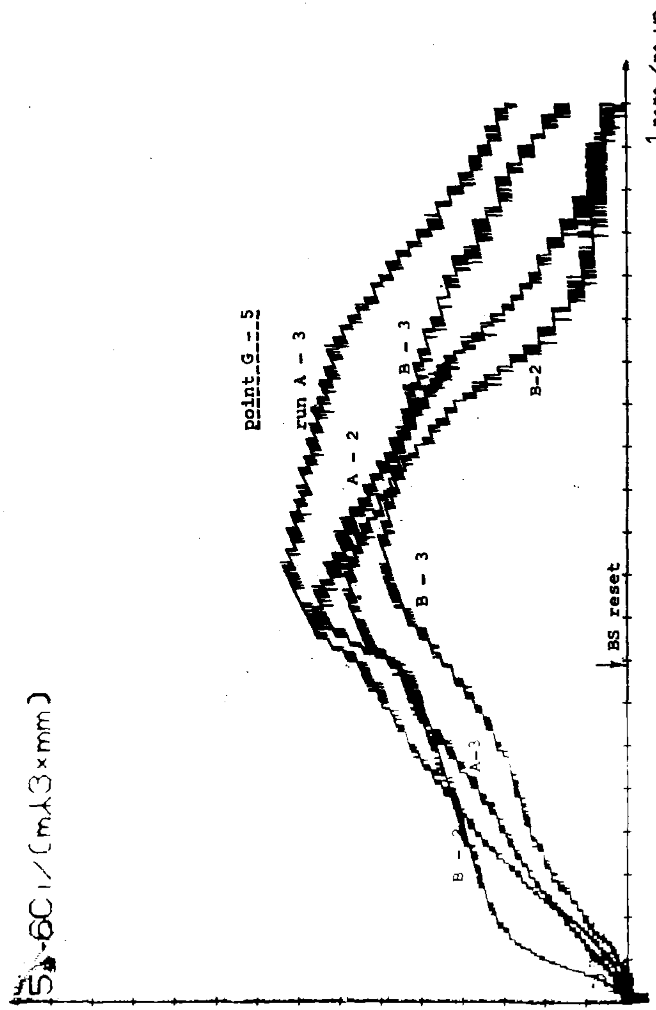


Fig. A II - 5.

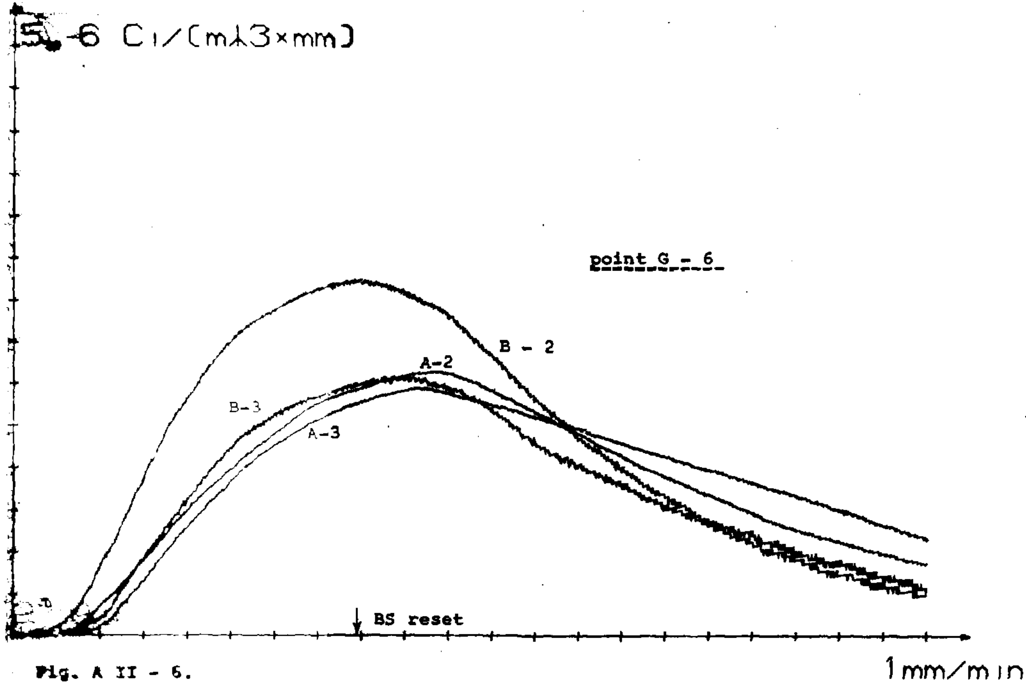


Fig. A II - 6.

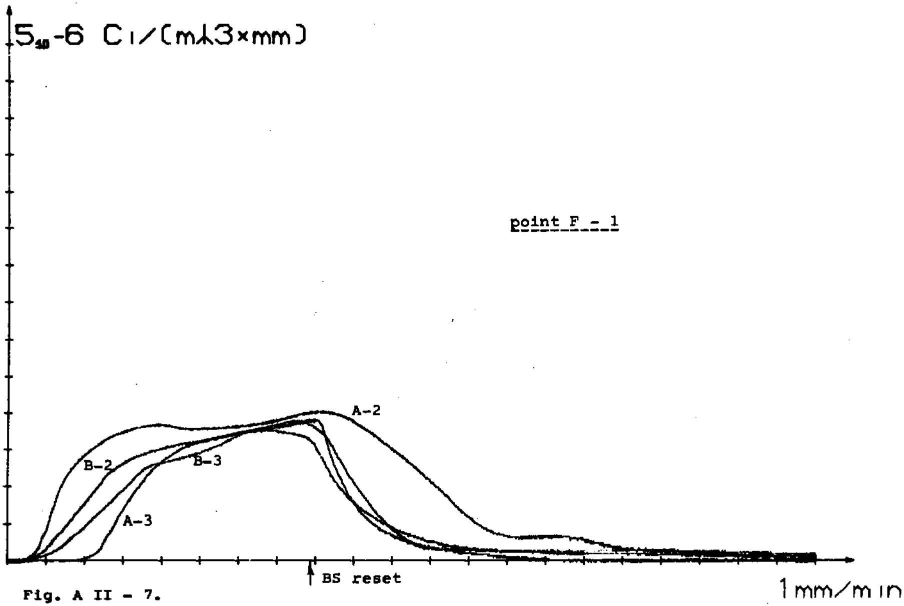
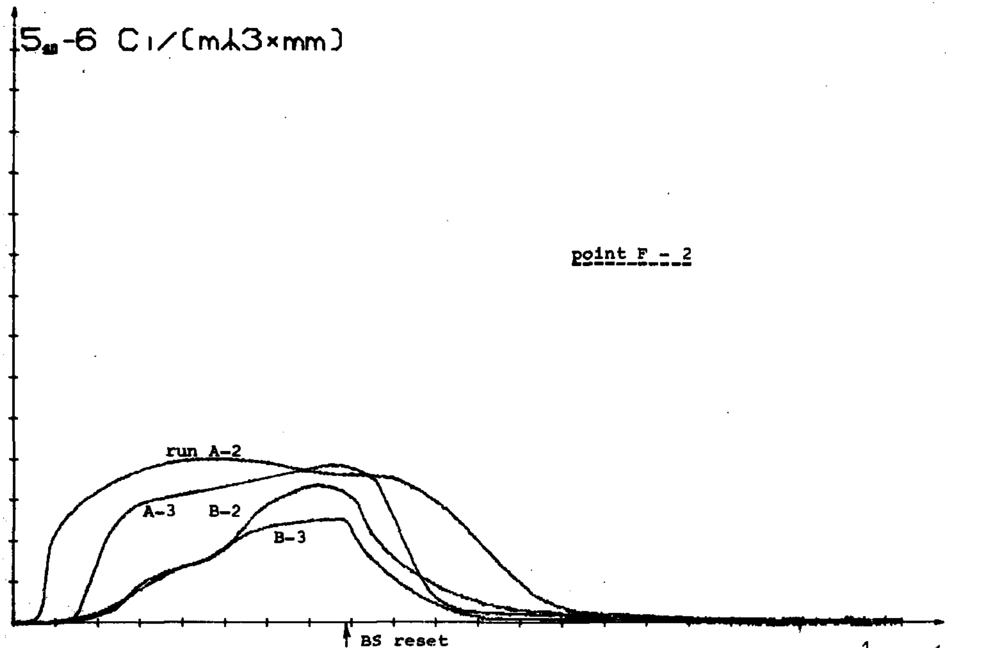


Fig. A II - 7.



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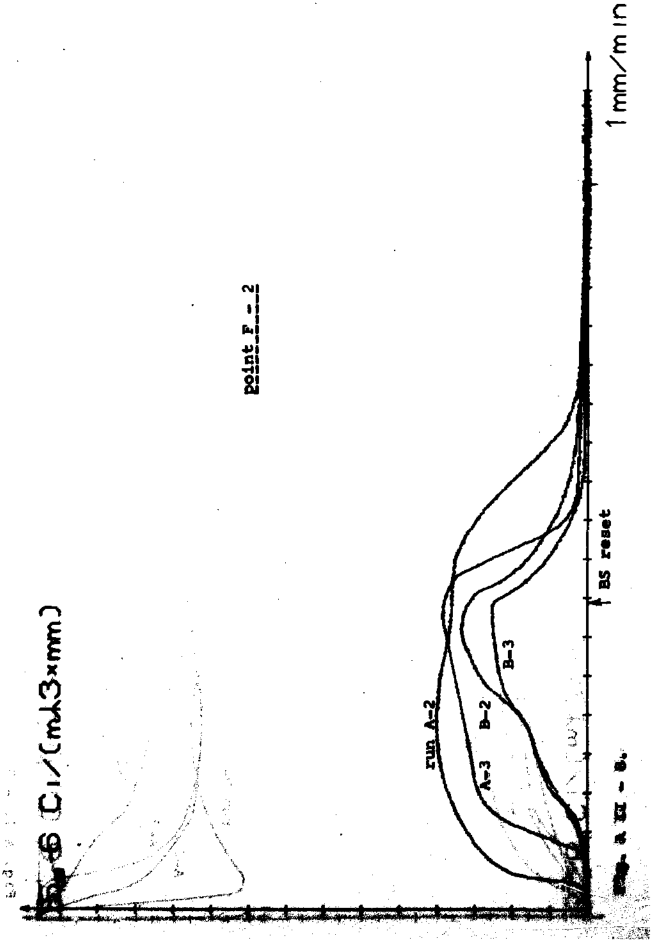
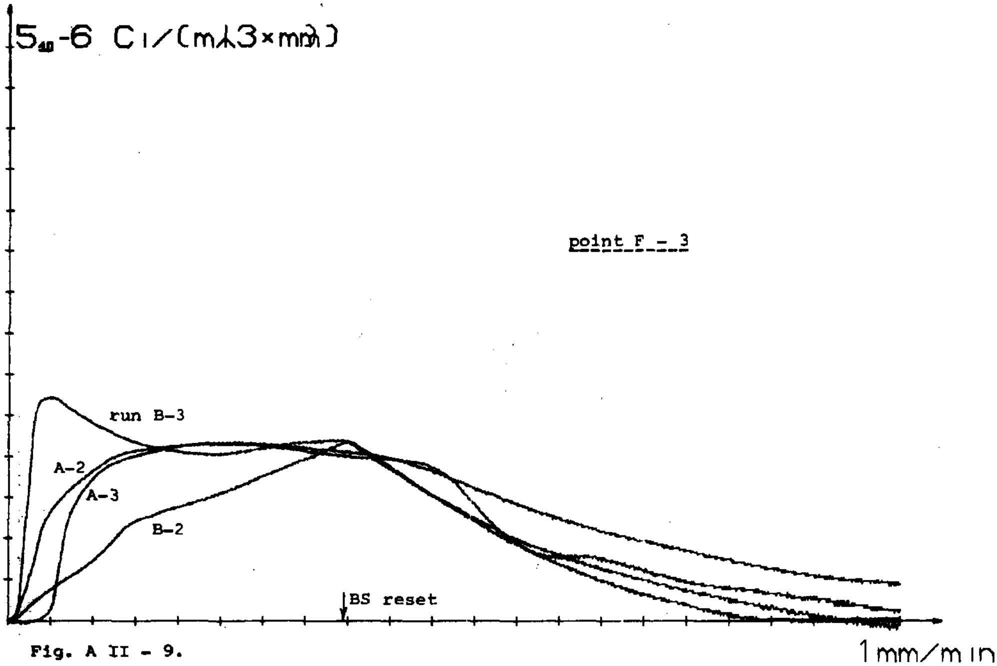

Point F - 2
run A-2
A-3
B-2
B-3
BS reset
1mm/min



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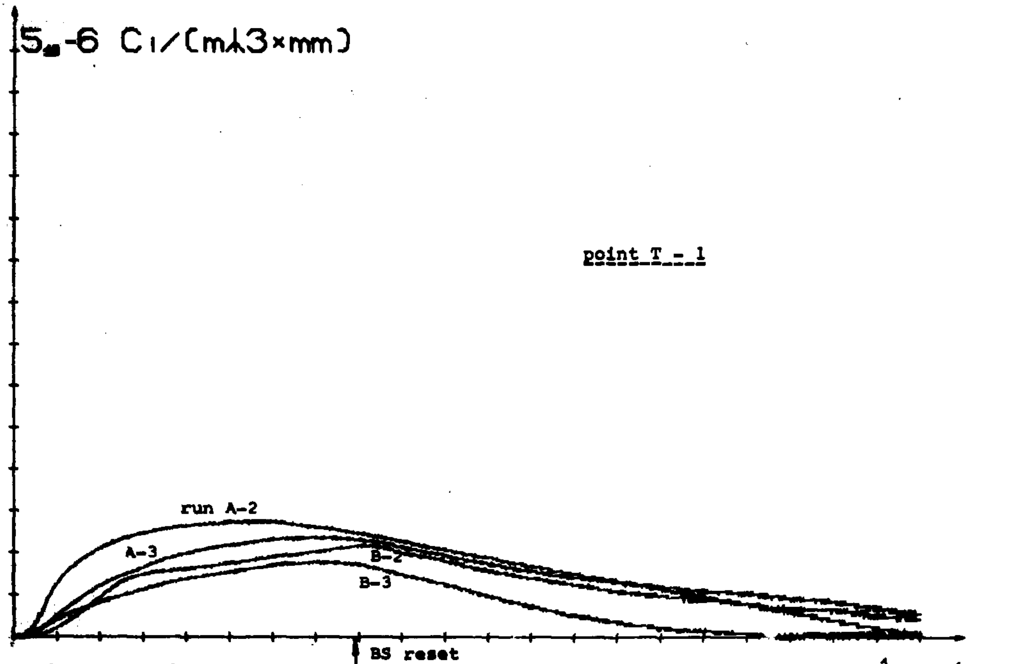

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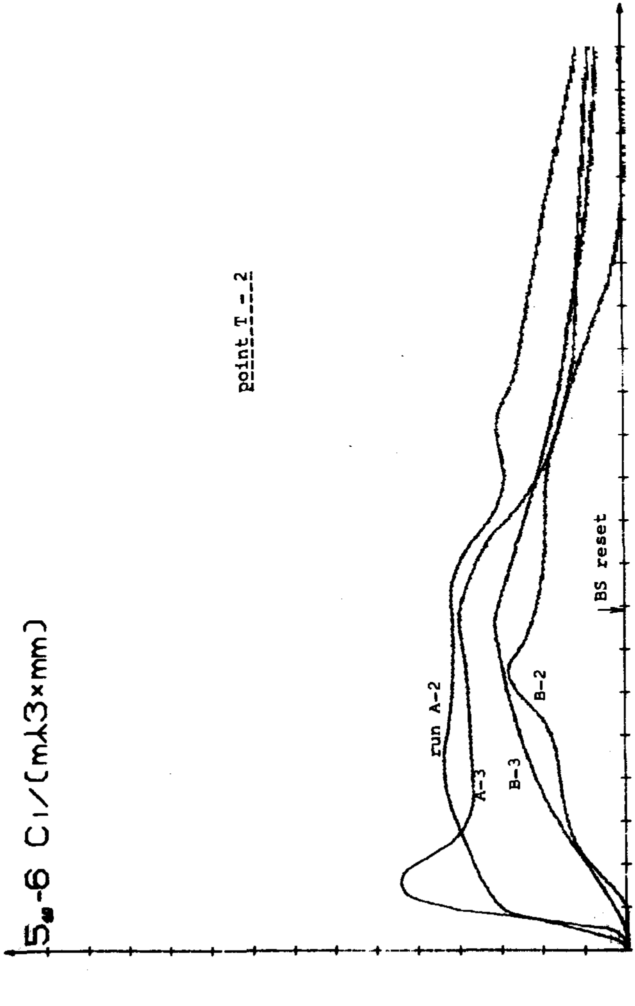

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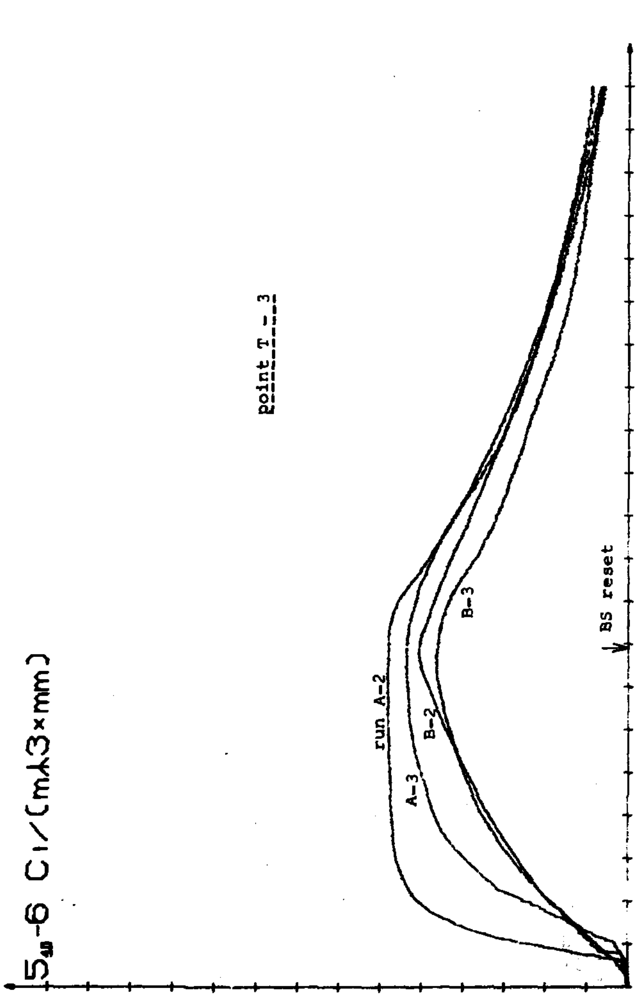

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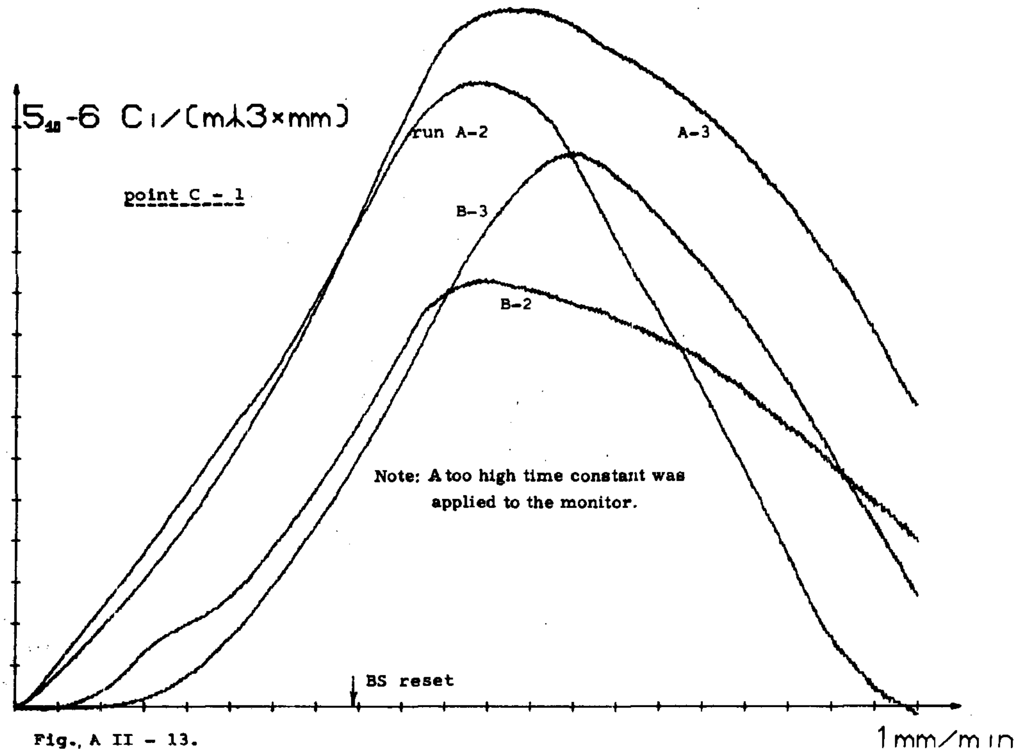


5$_{10}$-6 Ci/(mλ3×mm)
point C - 1
run A-2
A-3
B-3
B-2
Note: A too high time constant was applied to the monitor.
BS reset
1mm/min

Fig., A II - 13.

Appendix III

Figures AIII-1 to AIII-14. Specific activity vs. time, gamma exposure rate (curves marked "g") and beta + gamma exposure rate (curves marked "b+ g") vs. time after release of activity standardized to 1 C.

Run A-2 - release to top void, BS before release.

G-1 to G-6 - measurement points at ground floor level.

F-1 to F-3 - measurement points at first floor level.

T-1 to T-3 - measurement points at reactor top level.

C-1 - measurement point at crane balcony level.

T-E - measurement point inside the elevator at the reactor top position.

Note: 1. At C-1 a too high time constant was applied to the monitor measuring specific activity.

2. The exposure rate at C-1 was measured at the position of the activity detector (at the top balcony level) and not at the suction point.

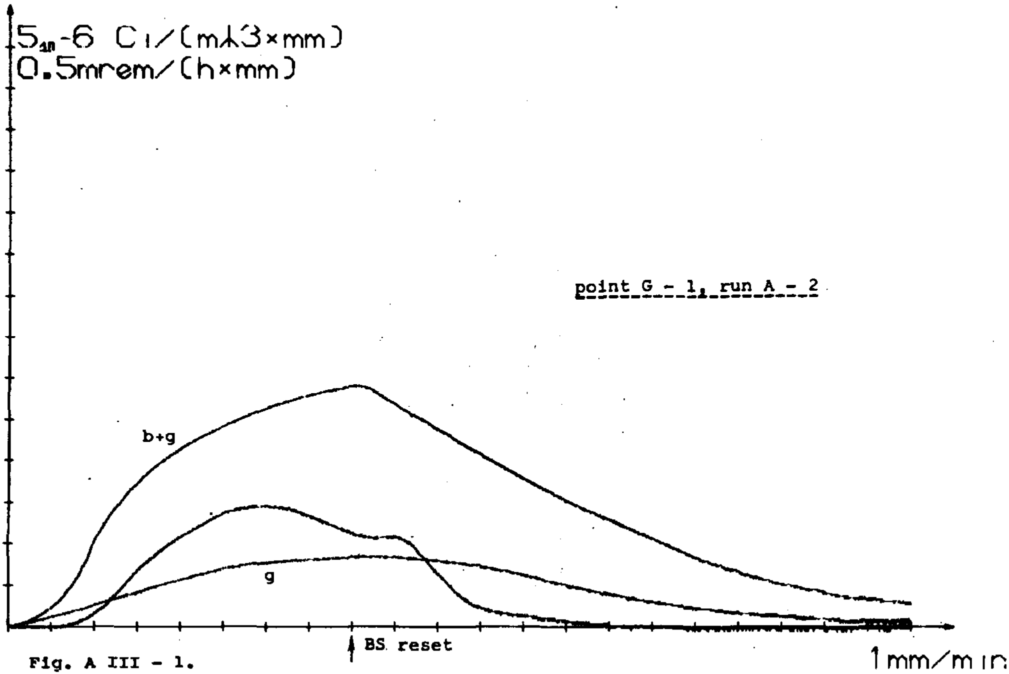


Fig. A III - 1.

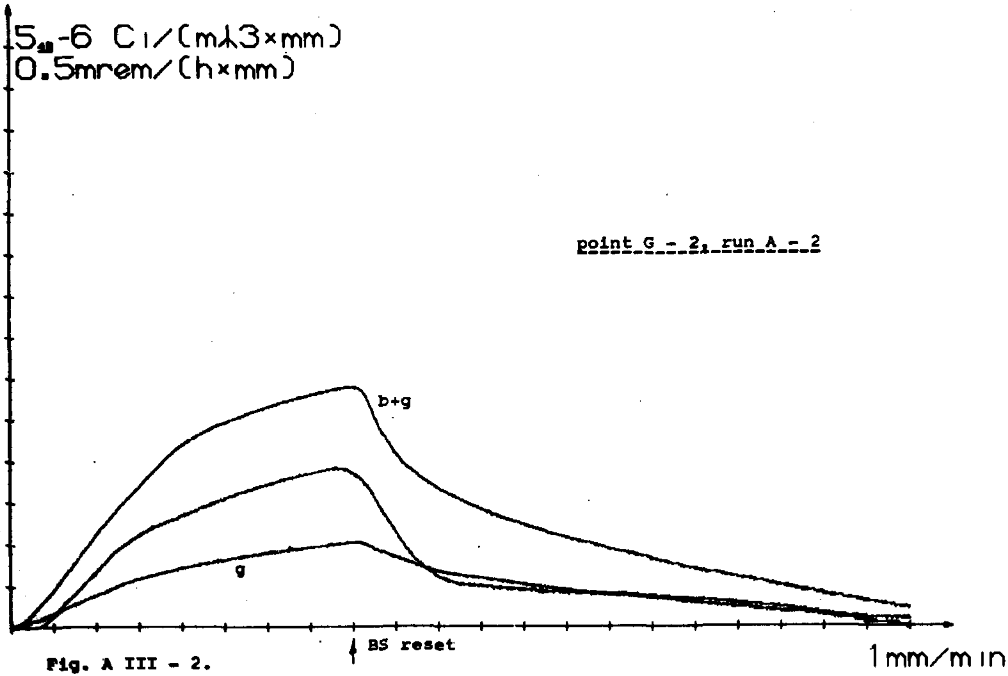


Fig. A III - 2.

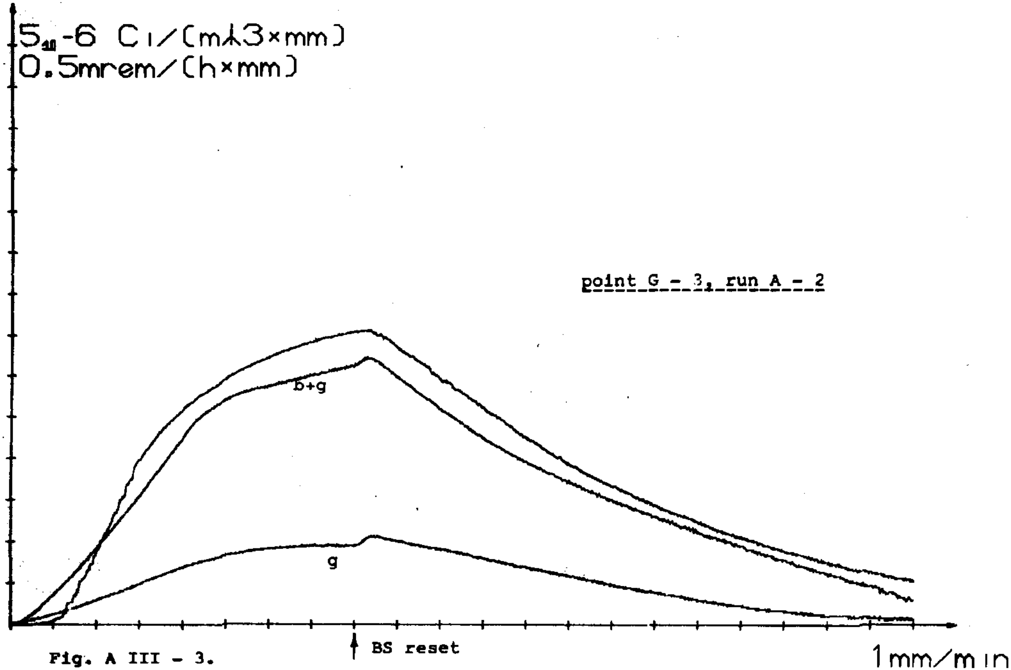


Fig. A III - 3.

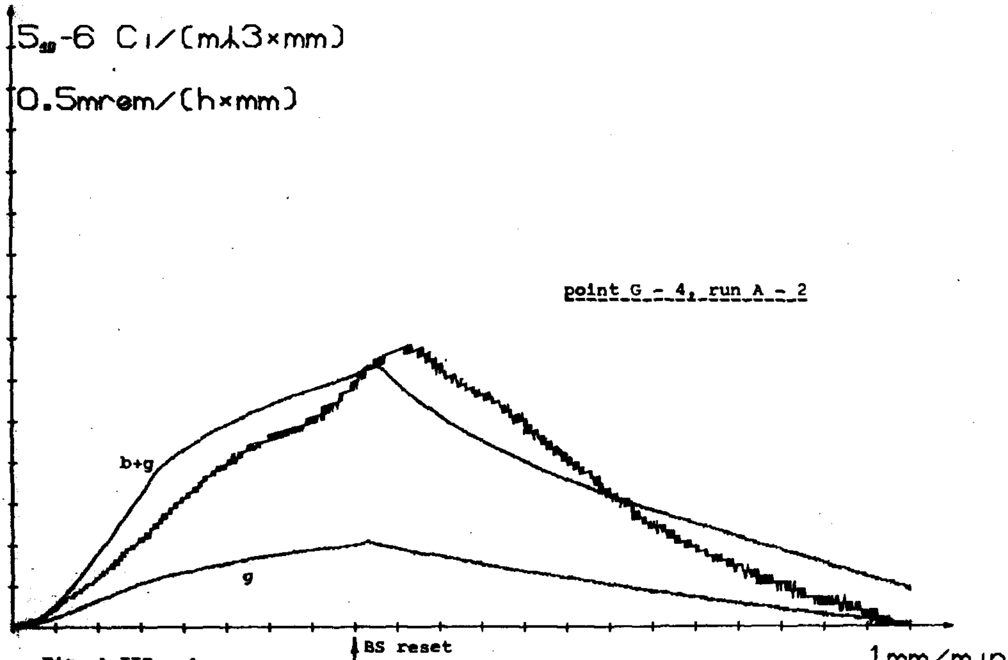


Fig. A III - 4.

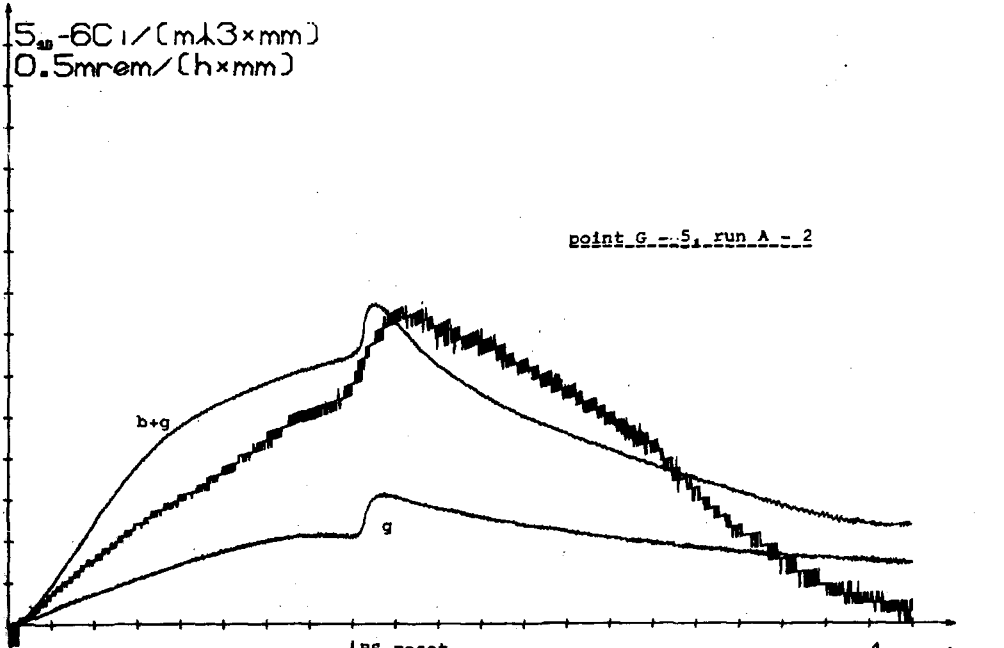


Fig. A III - 5.

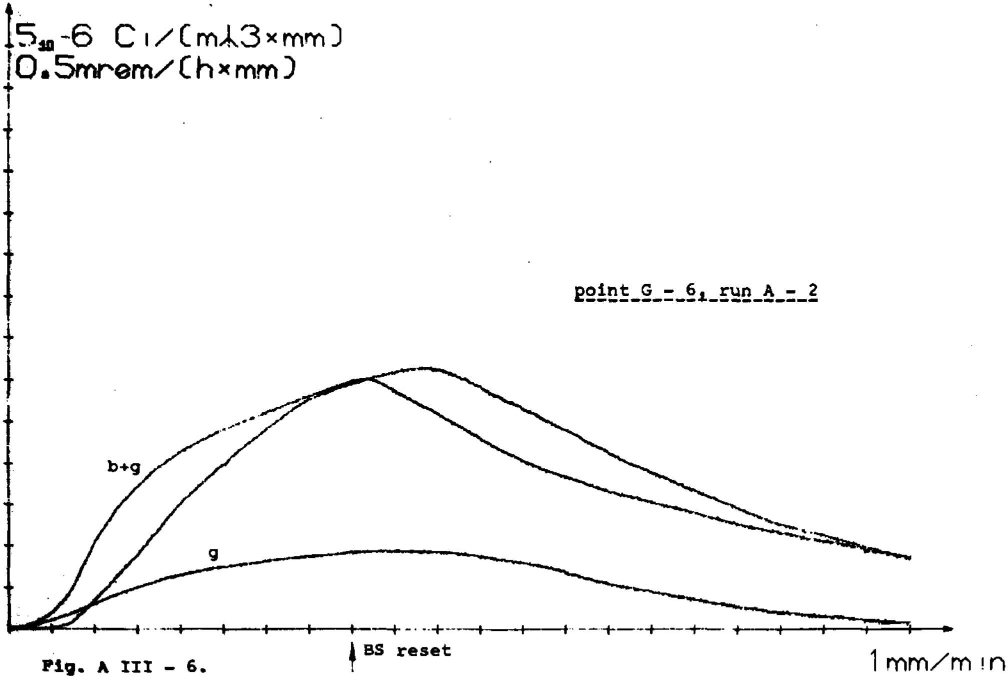

$5 \cdot 10^{-6}$ Ci/(m^3×mm)
0.5mrem/(h×mm)
point G - 6, run A - 2
b+g
g
BS reset
1mm/min

Fig. A III - 6.

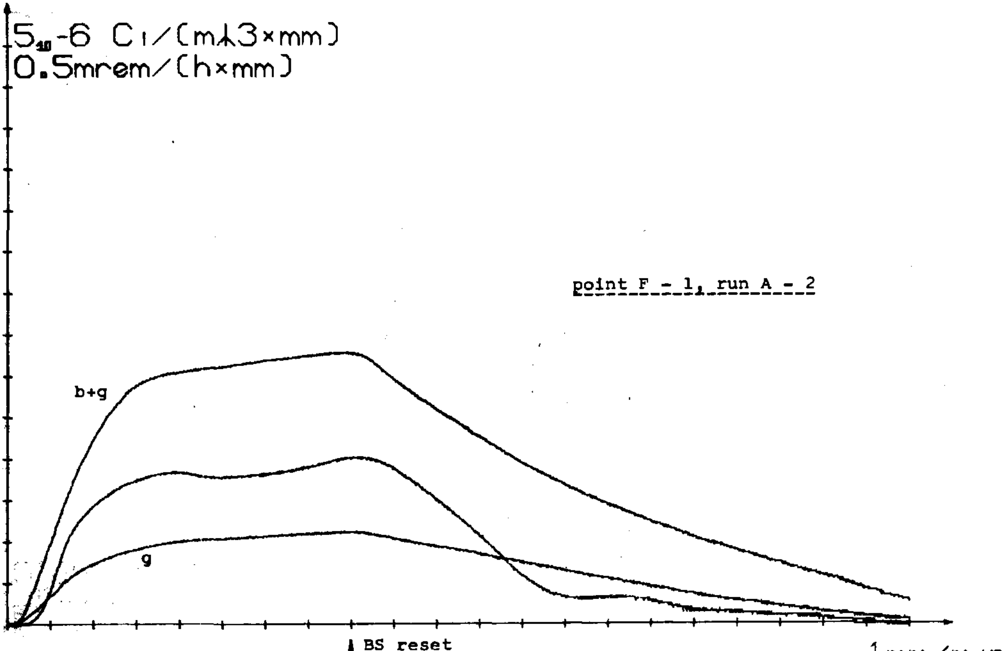
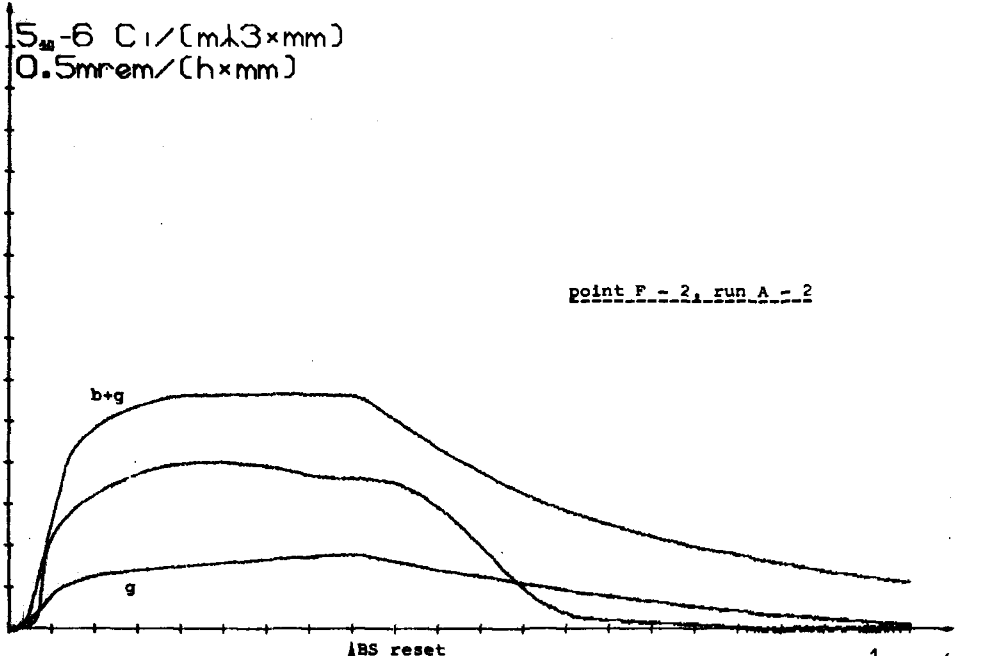


Fig. A III - 7.



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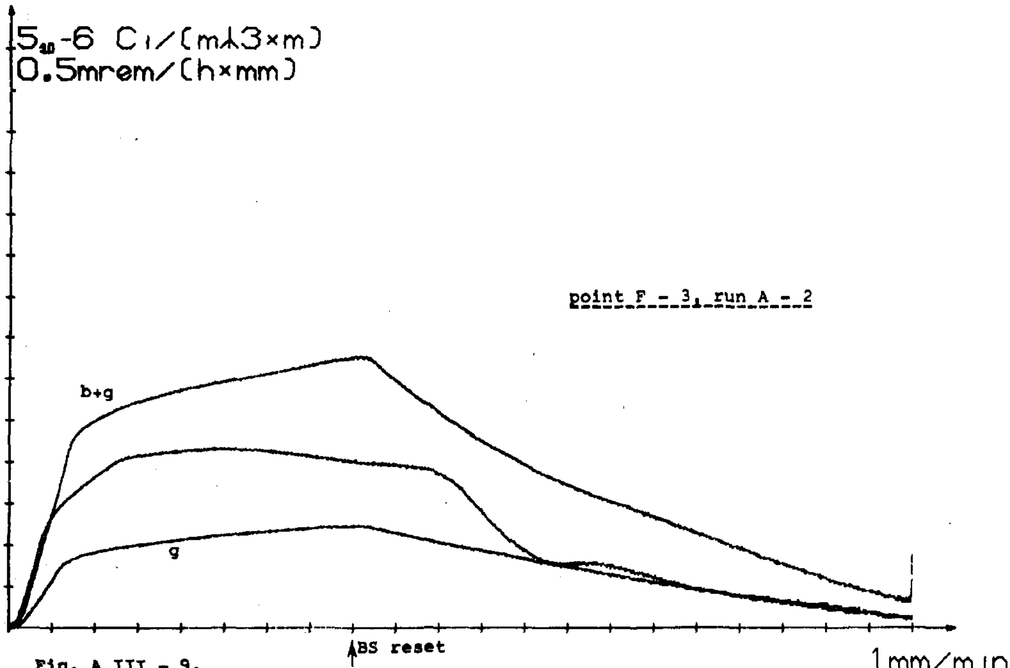

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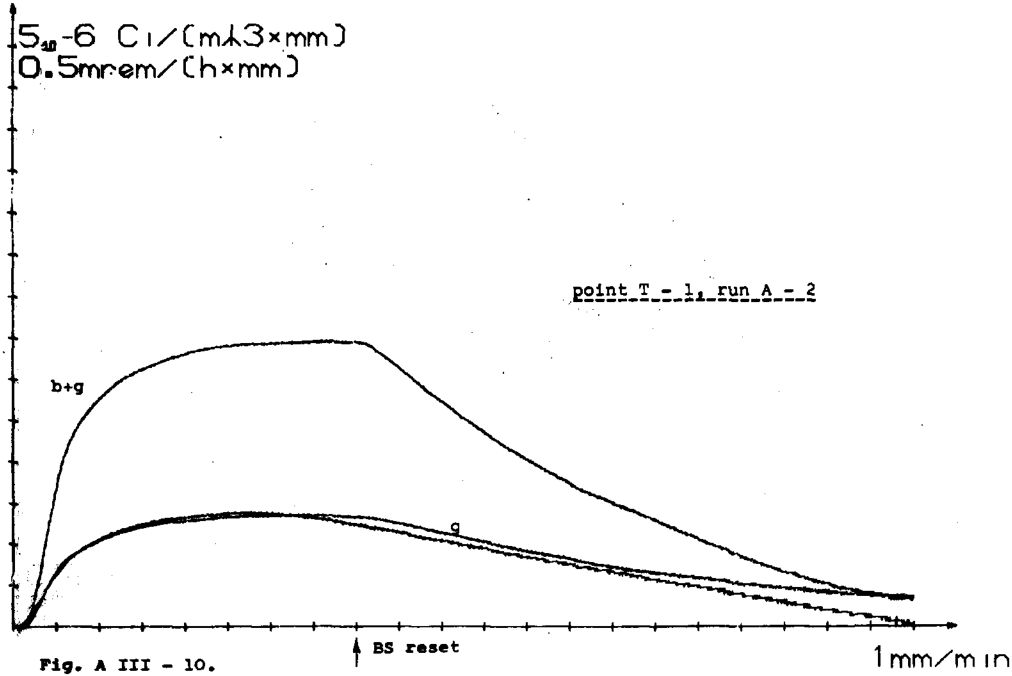

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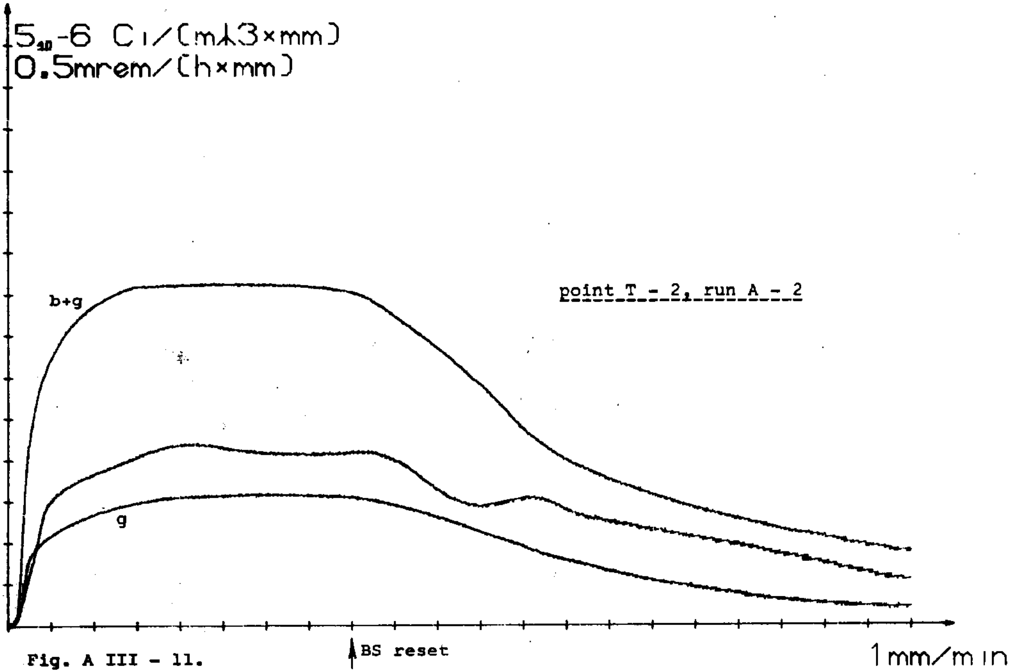


Fig. A III - 11.

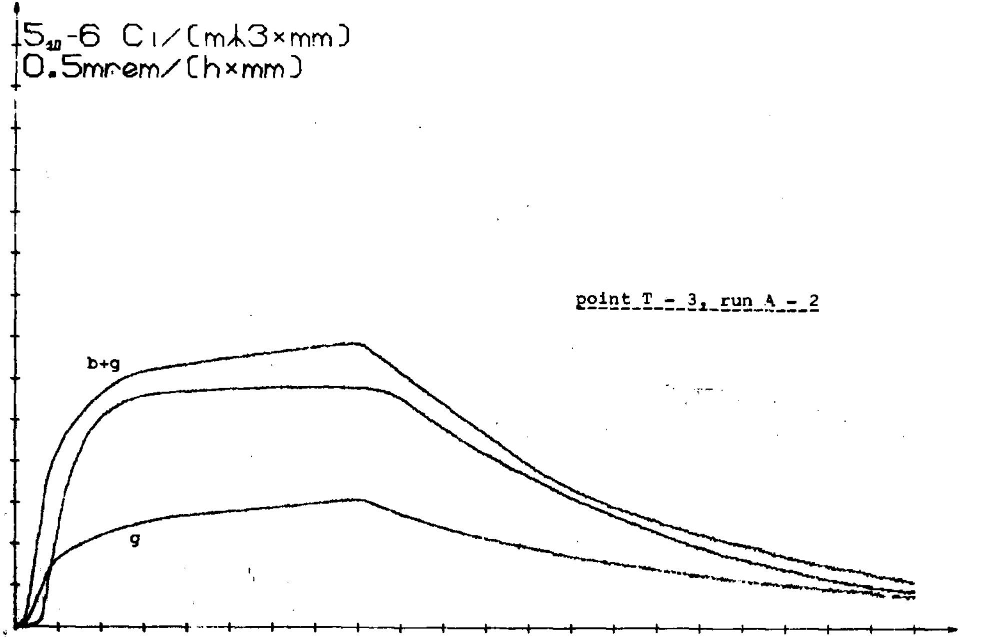
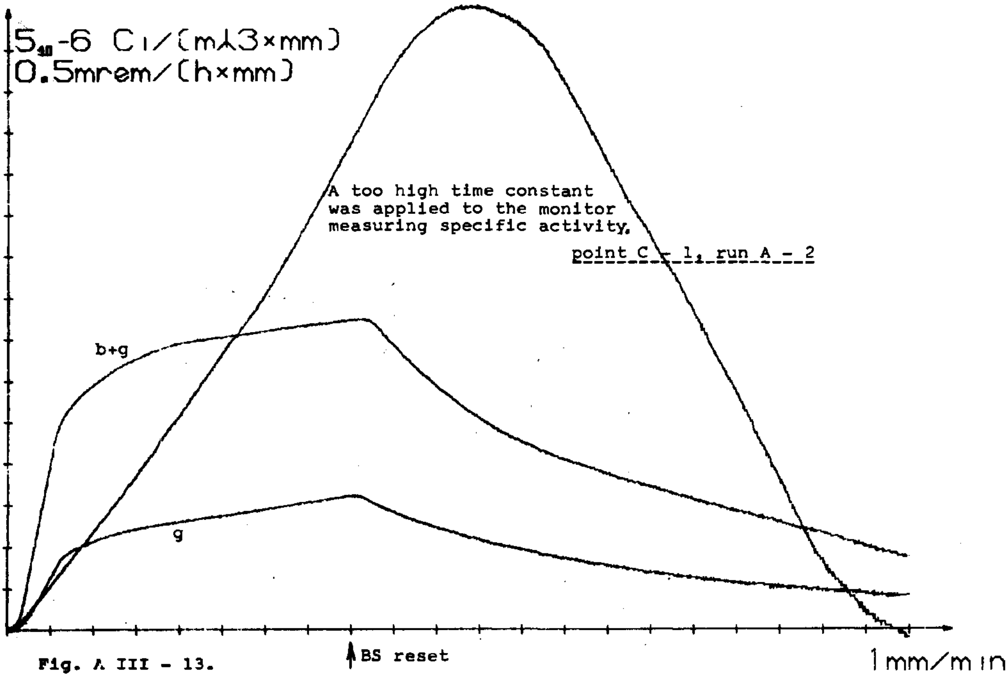
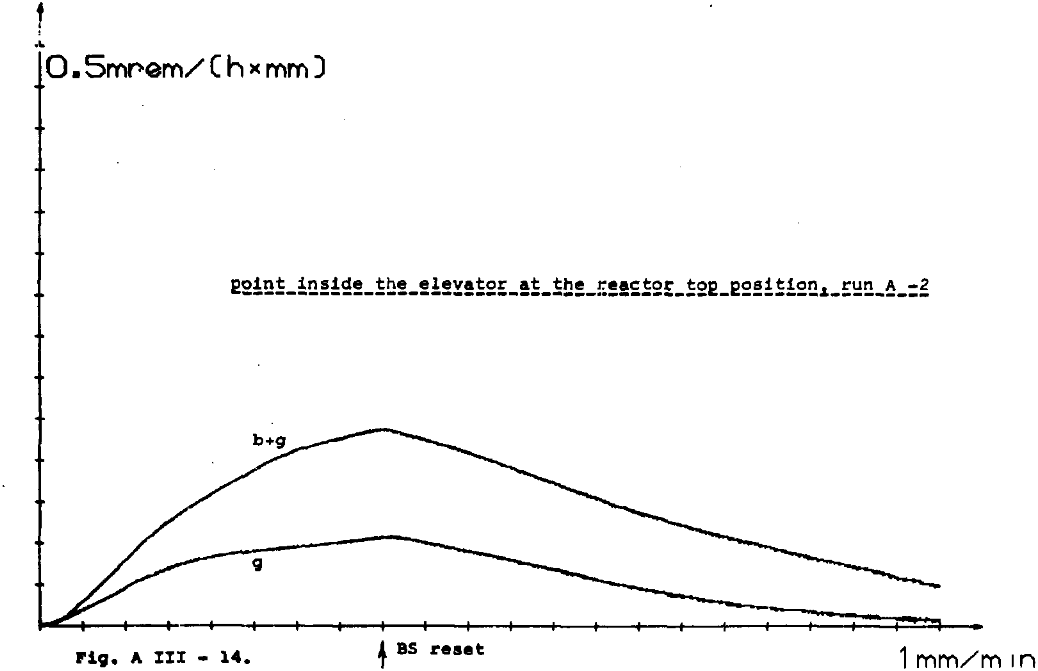


Fig. A III - 12.



5₁₀-6 Ci/(ml3×mm)
0.5mrem/(h×mm)
A too high time constant
was applied to the monitor
measuring specific activity.
point C - 1, run A - 2
b+g
g
BS reset
1mm/min

Fig. A III - 13.



0.5mrem/(h×mm)
point inside the elevator at the reactor top position, run A -2
b+g
g
BS reset
1mm/min

Fig. A III - 14.

Appendix IV

Figures A-IV-1 to A-IV-36. Specific activity vs. time after release of activity standardized to 1 C.
A-runs: release to top void,
B-runs: release to D_2O-room.

Run A4-c - BS established and CRV and AA stopped manually from control room when approx. 1/10 BS limit (10 mR/h) was reached after release. Active ventilation mainly from top void.

Run A4-d - BS established when approx. 1/20 BS limit was reached after release. Active ventilation mainly from D_2O-room.

Run A4-e - BS established when approx. 1/10 BS limit was reached after release. Active ventilation mainly from top void.

Run A4-f - BS established and CRV off when 1/10 BS limit was reached after release. Active ventilation mainly from top void.

Run B4-a - normal ventilation conditions. Active ventilation mainly from top void.

Run B4-c - like A4-c.

Run B4-e - like A4-e.

Run B4-f - like A4-f.

Run B4d-a - like B4-a, but active vent. mainly from D_2O-room.

Run B4d-c - like B4-c, - - - - - - -

Run B4d-e - like B4-e, - - - - - - -

Run B4d-f - like B4-f, - - - - - - -

G-1 to G-6 - measurement points at ground floor level.

F-1 to F-3 - - - - first floor level.

T-1 to T-3 - - - - reactor top level.

C-1 - - - - crane balcony level.

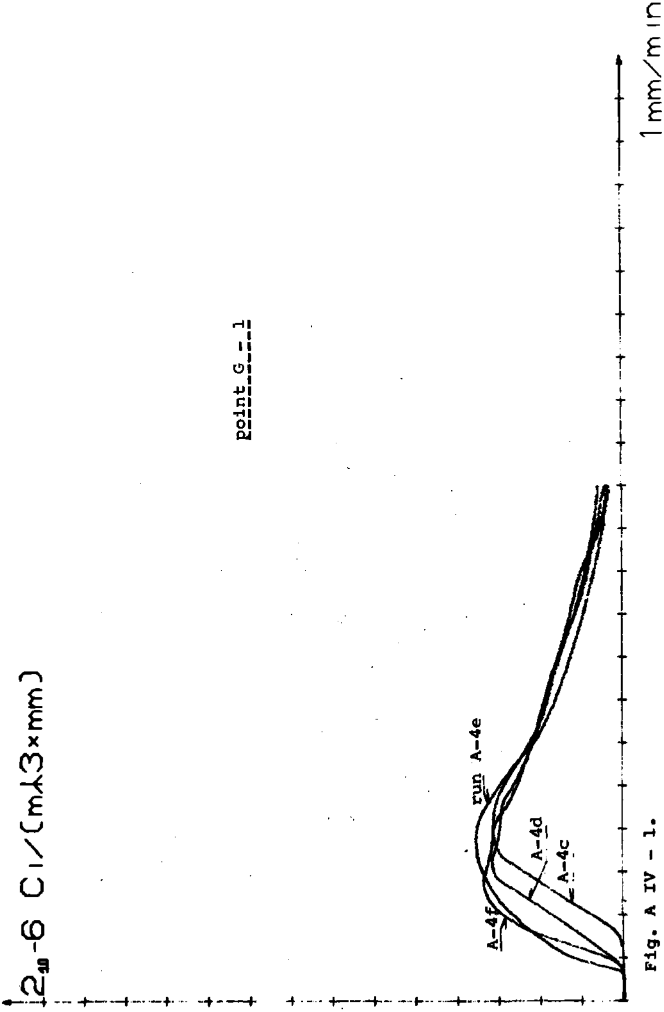


Fig. A IV - 1.

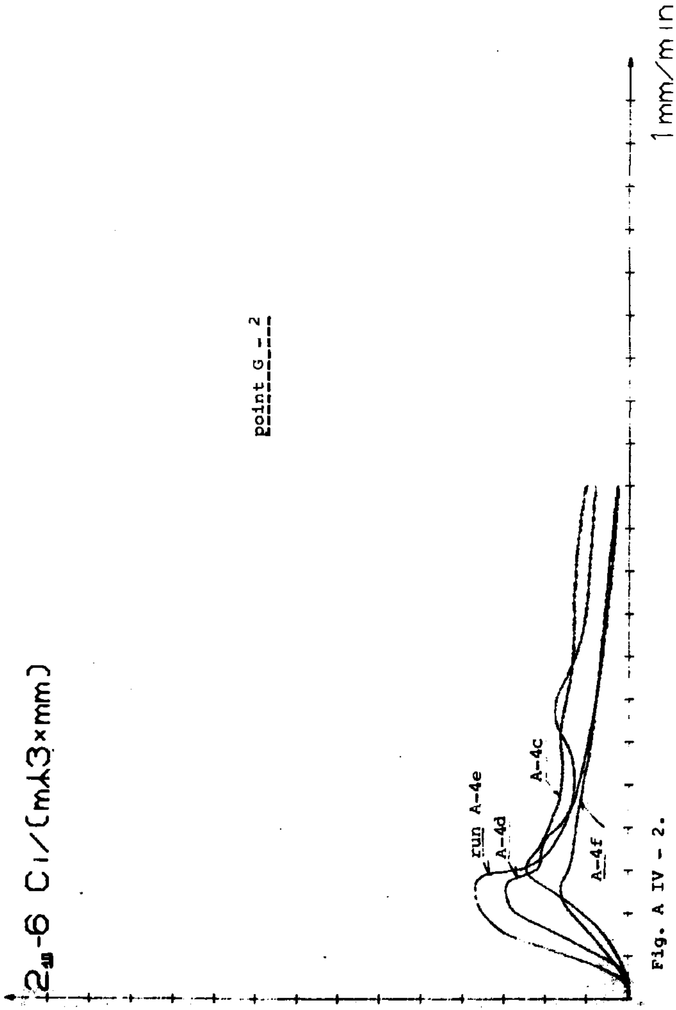


Fig. A IV - 2.

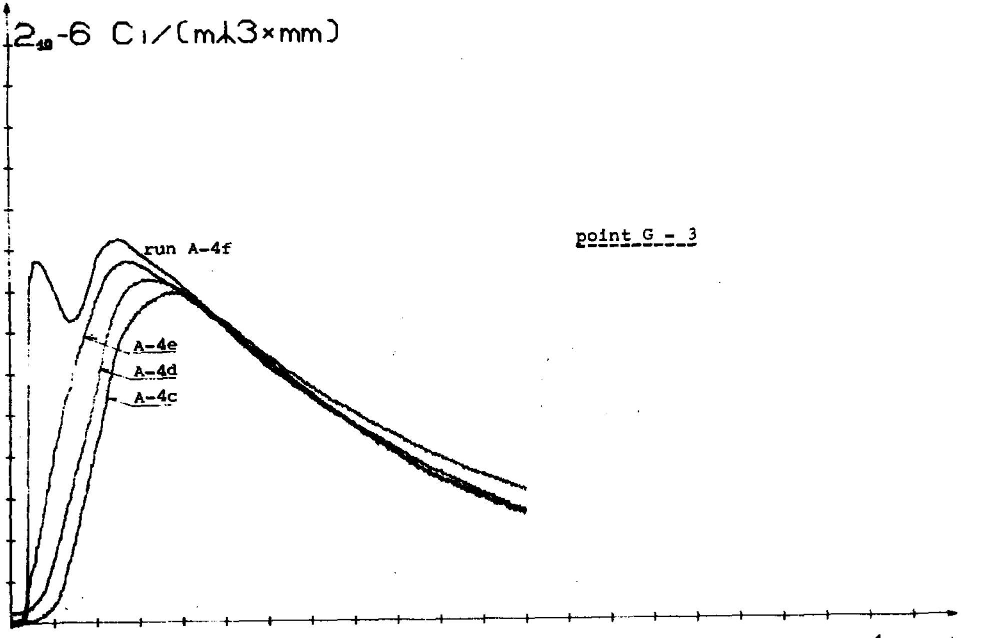


Fig. A IV - 3.

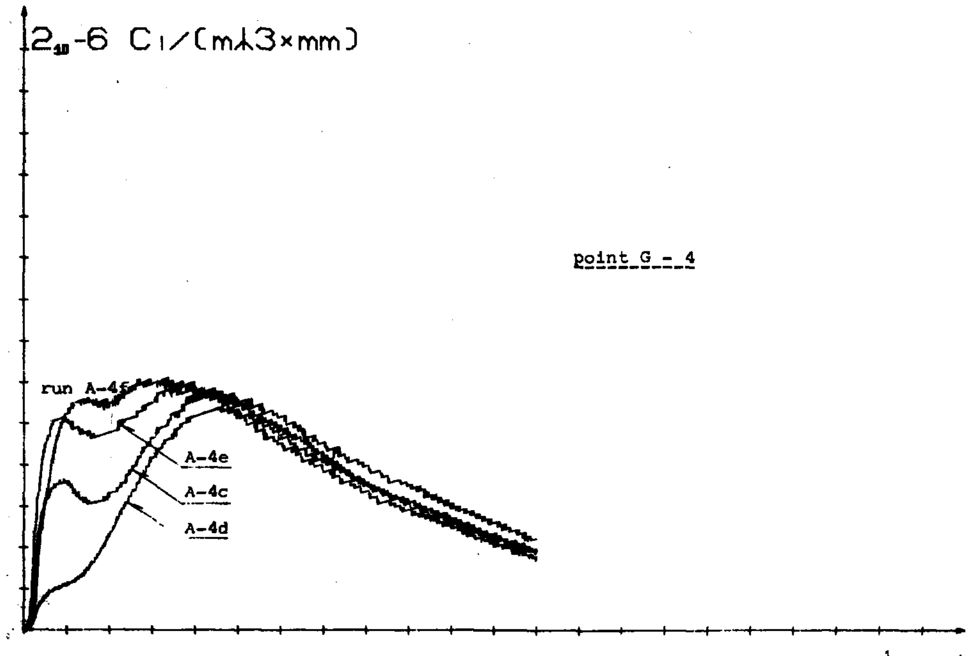


Fig. A IV - 4.

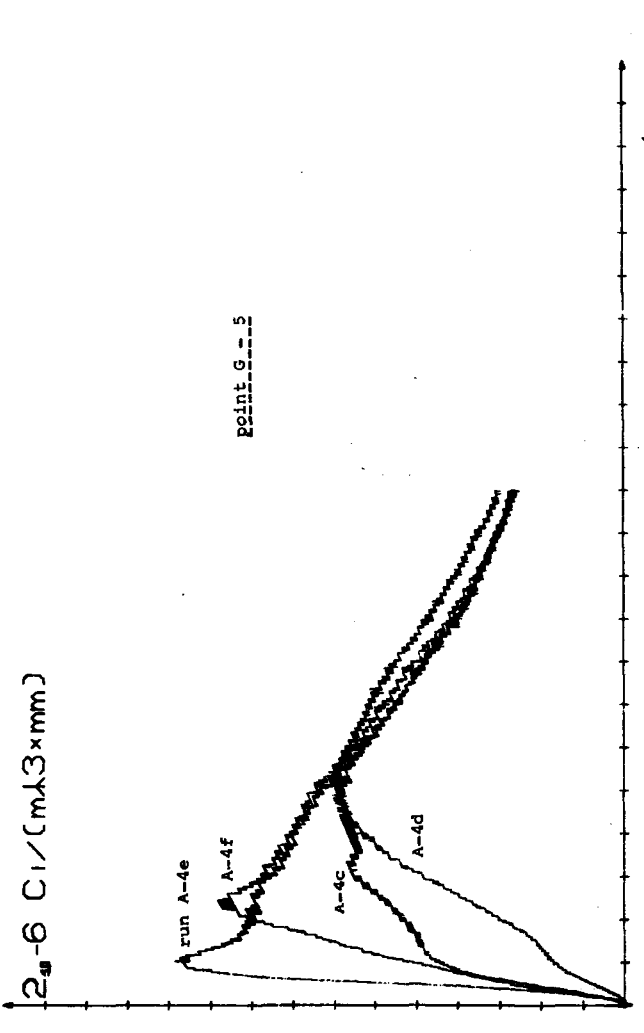


Fig. A IV - 5.

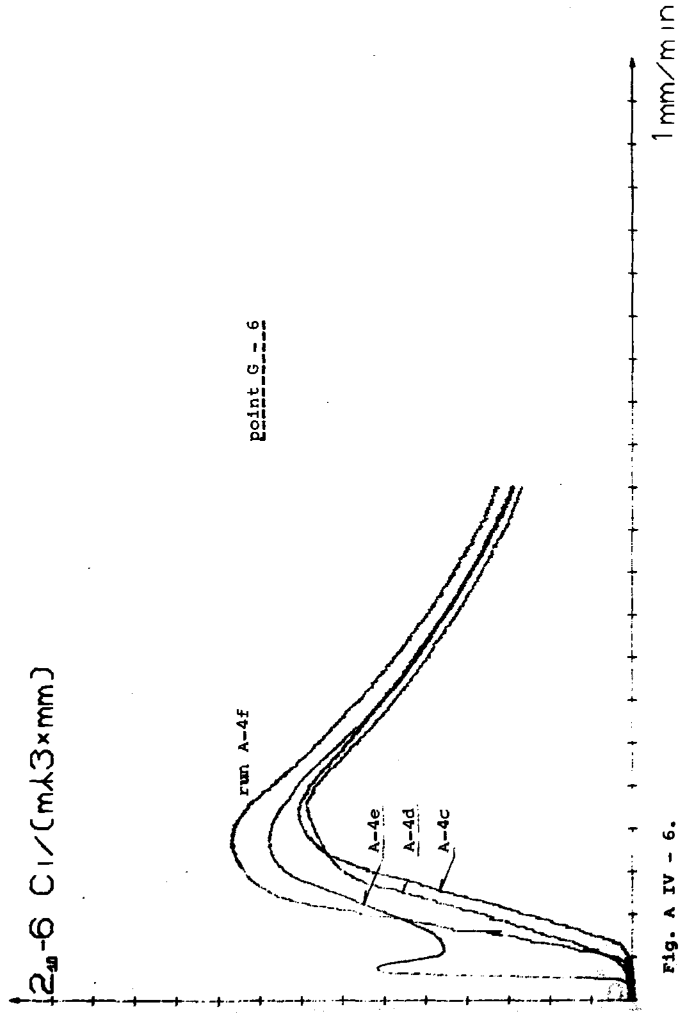


Fig. A IV - 6.

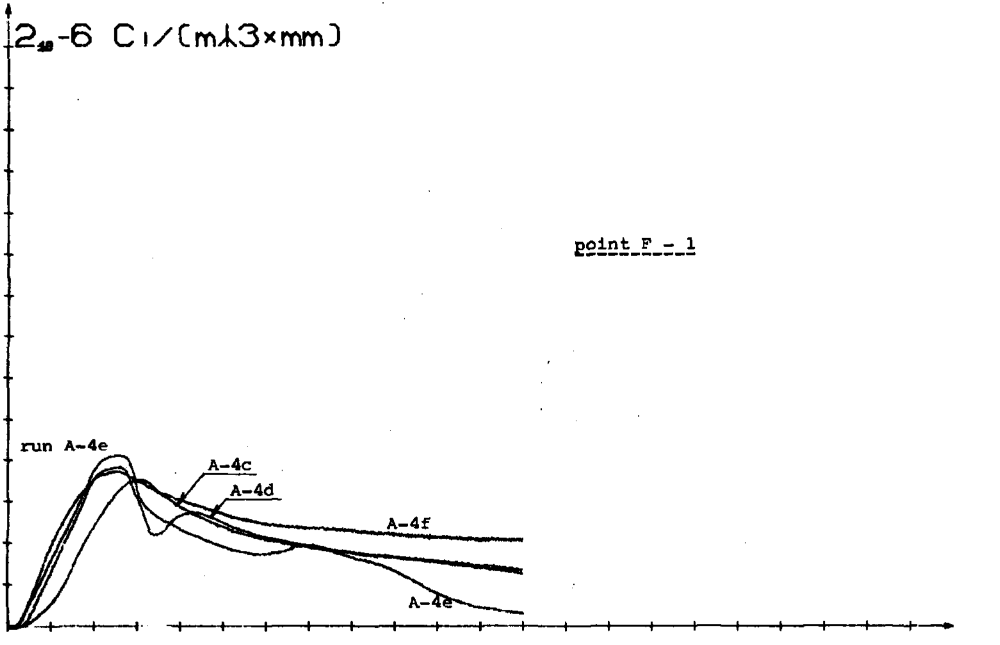


Fig. A IV - 7.

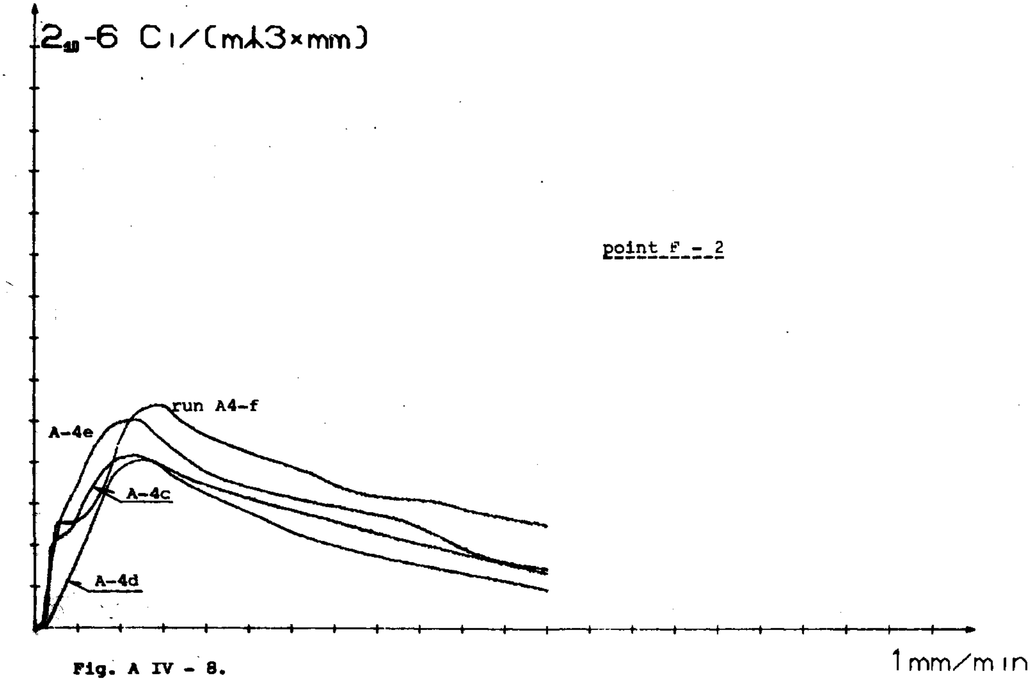


Fig. A IV - 8.

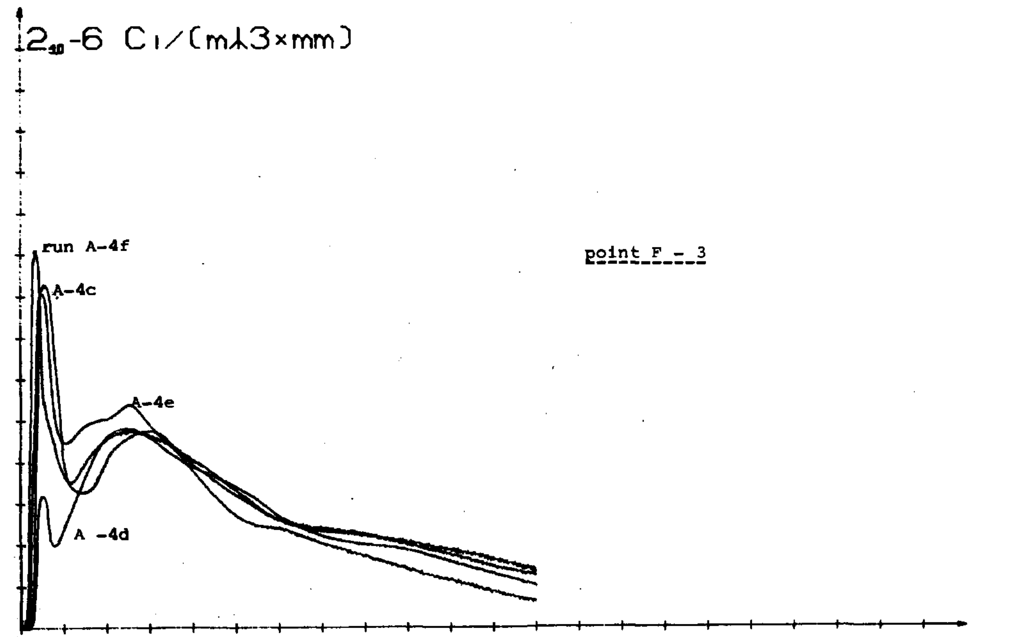


Fig. A IV - 9.

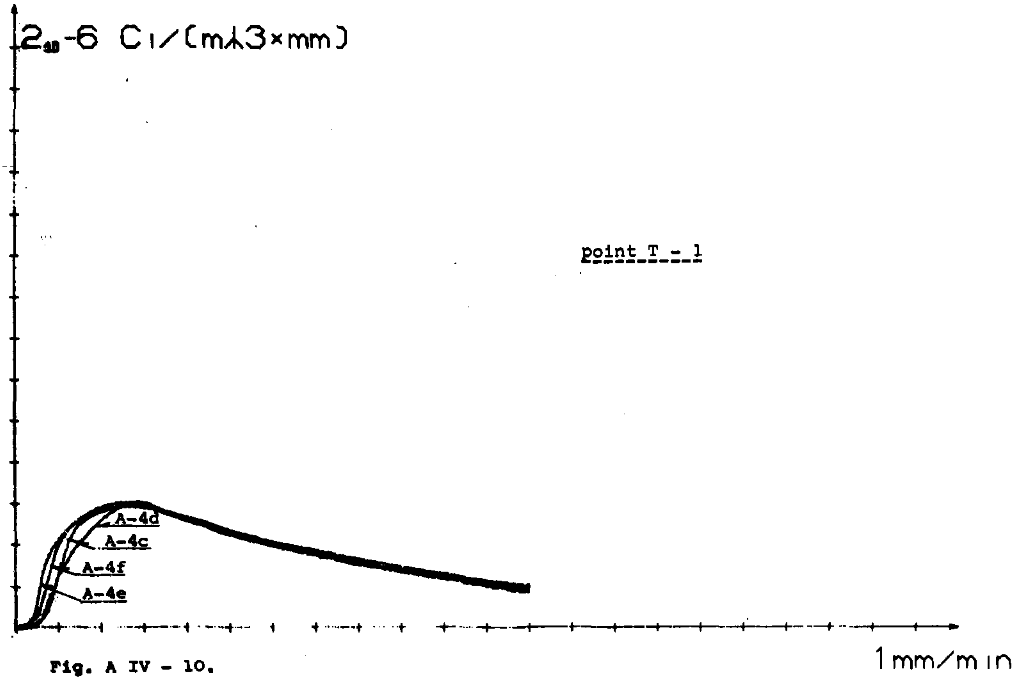


Fig. A IV - 10.

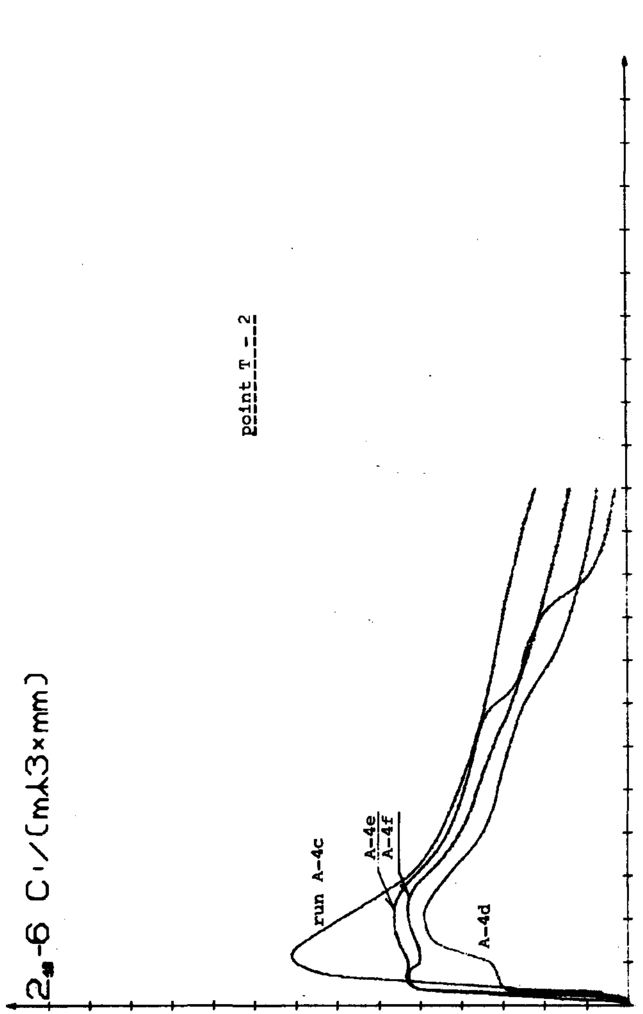


Fig. A IV - 11.

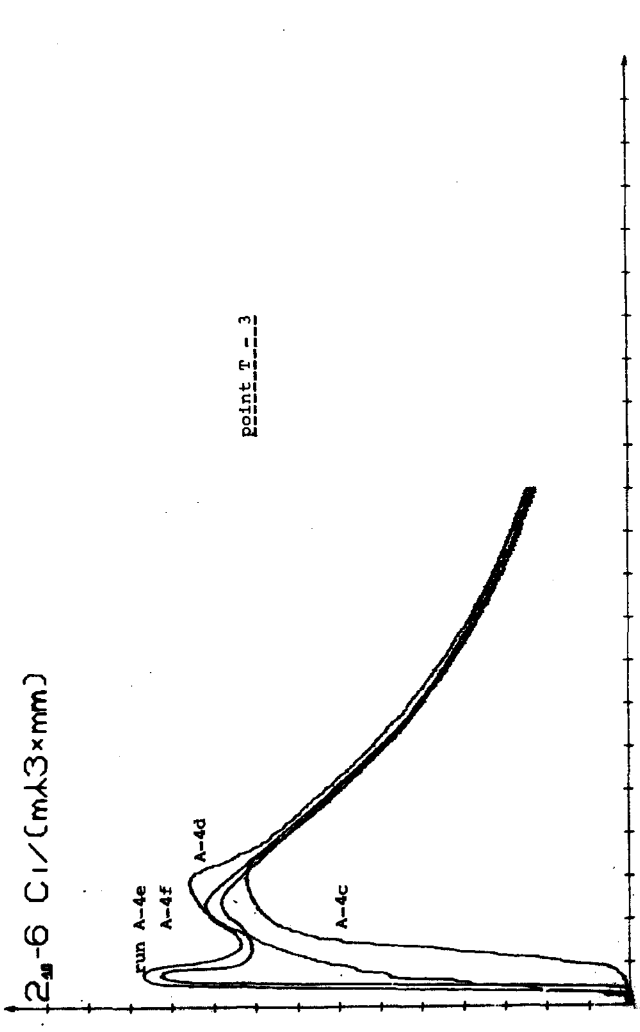


Fig. A IV - 12.

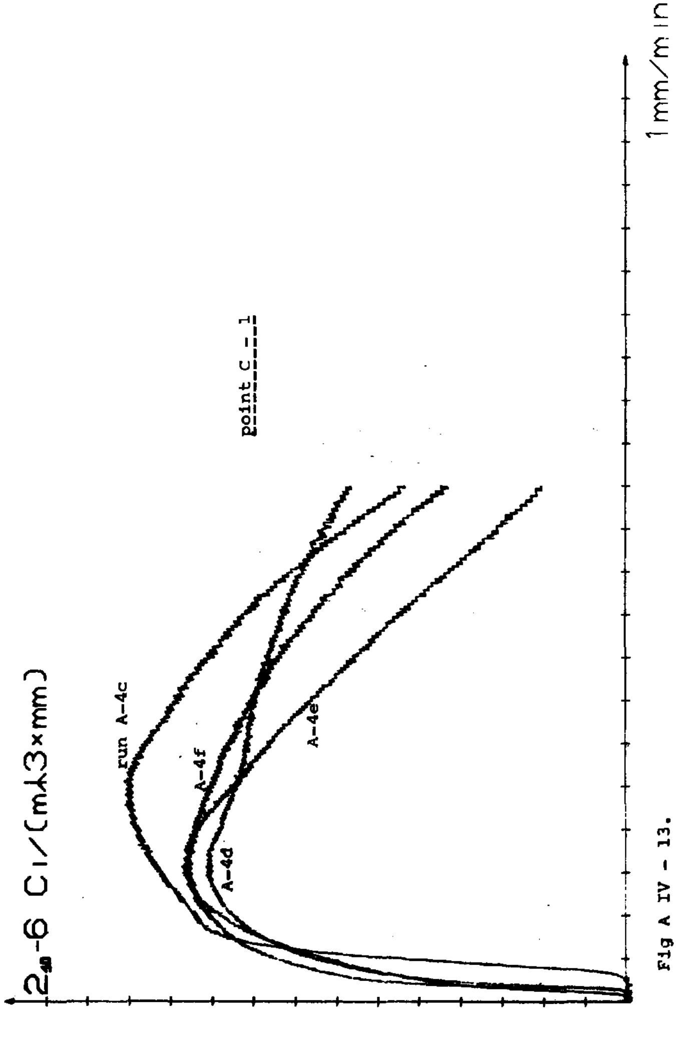


Fig A IV - 13.

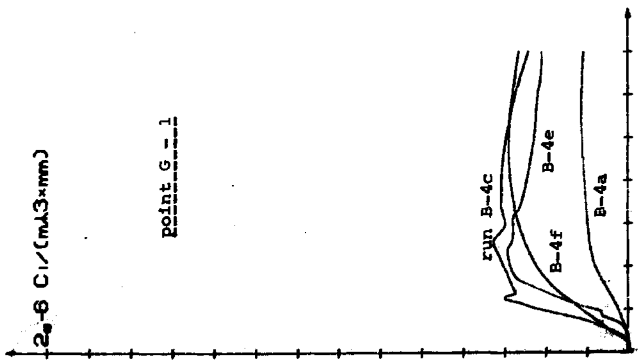


Fig. A IV - 14.

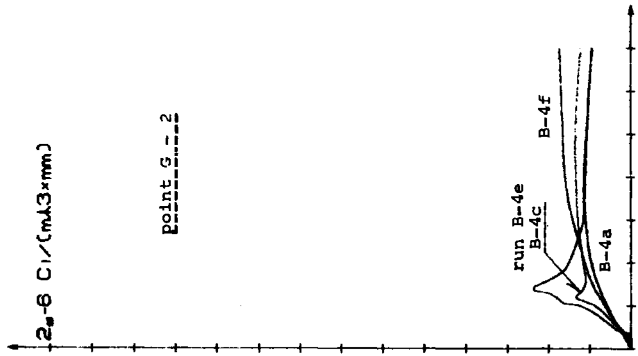


Fig. A IV - 15.

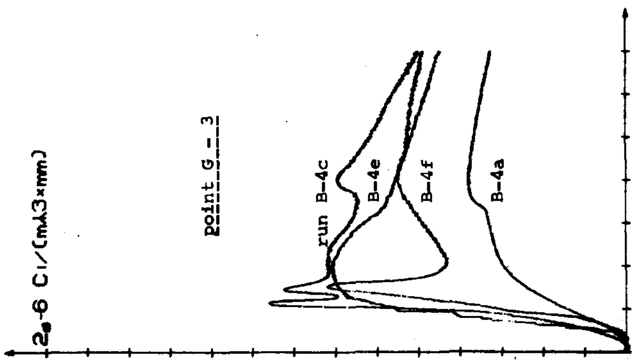


Fig. A IV - 16.

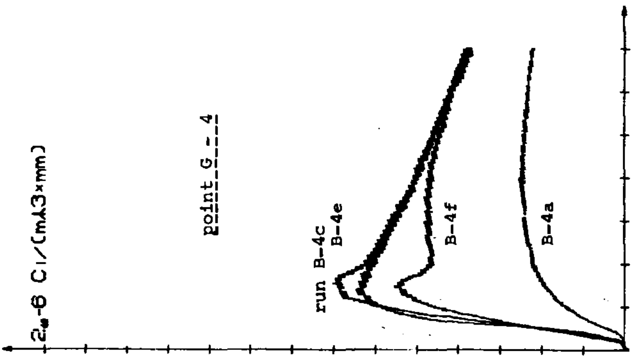


Fig. A IV - 17.

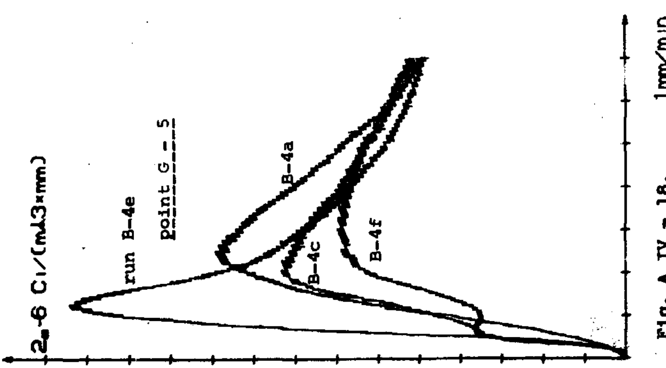


Fig. A IV - 18.

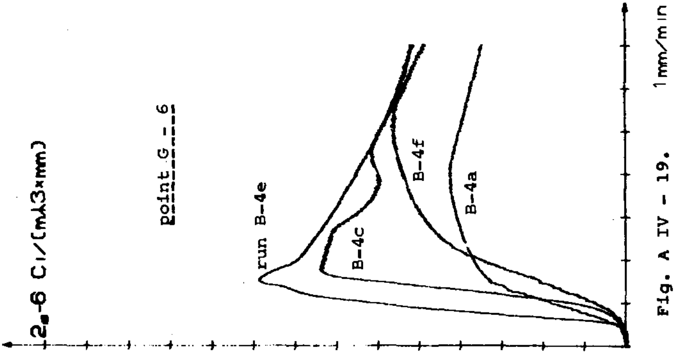


Fig. A IV - 19.

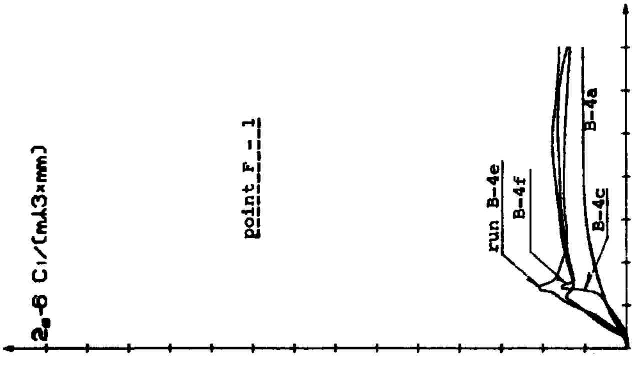


Fig. A IV - 20.

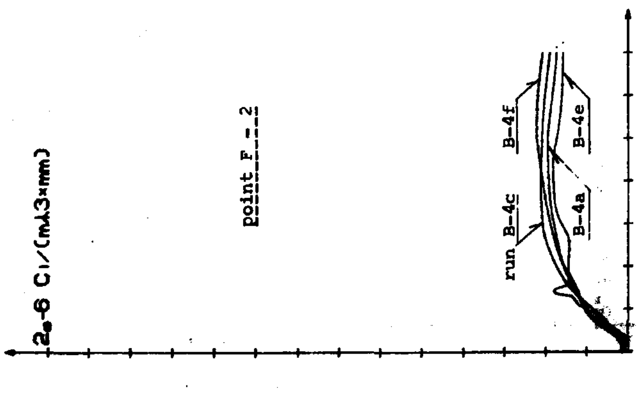


Fig. A IV - 21.

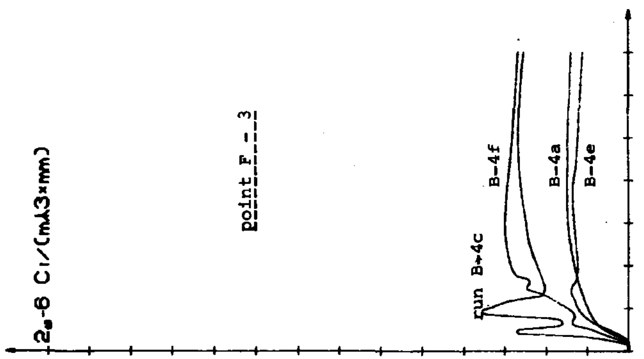


Fig. A IV - 22.

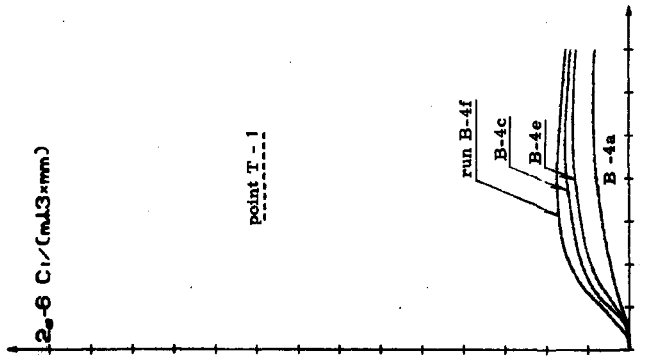


Fig. A IV - 23.

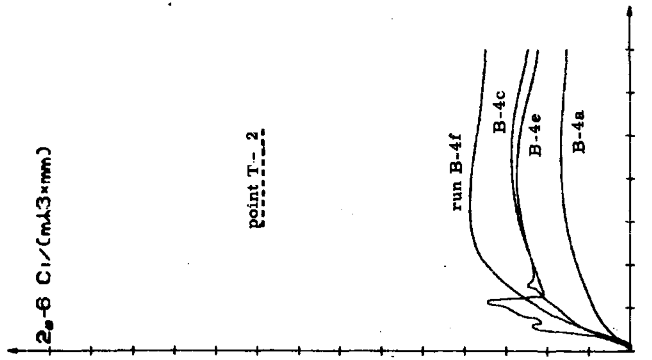
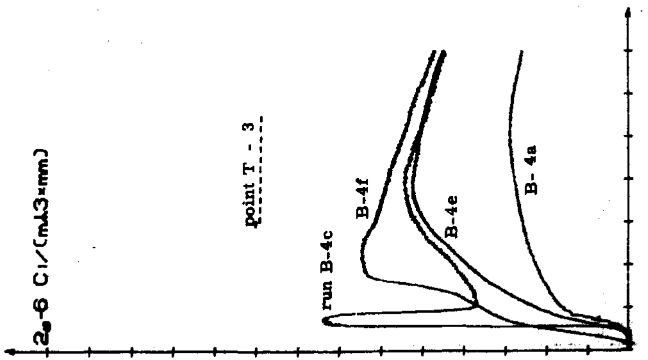


Fig. A IV - 24.



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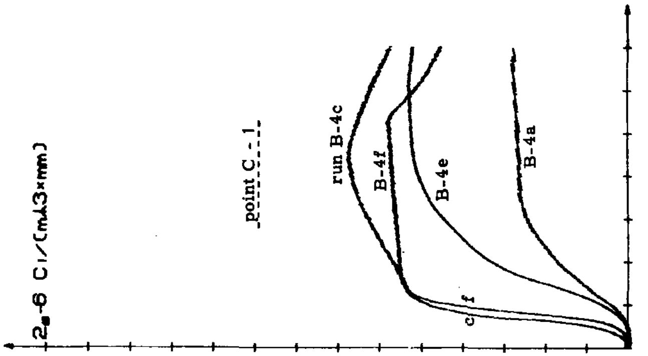

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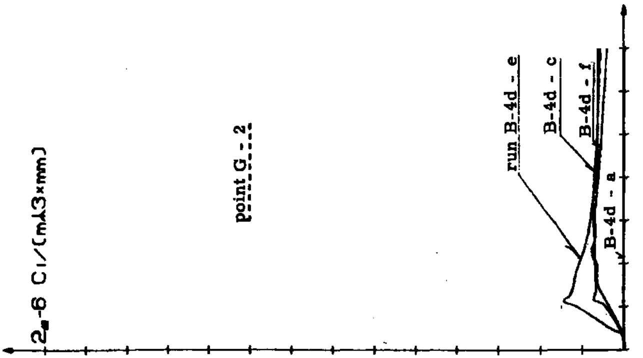


Fig. A IV - 28.

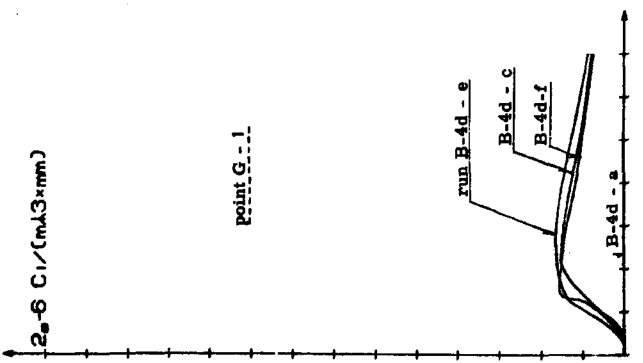


Fig. A IV - 27.

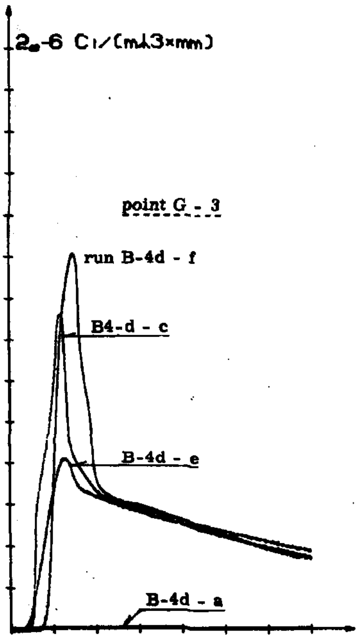


Fig. A IV - 29.

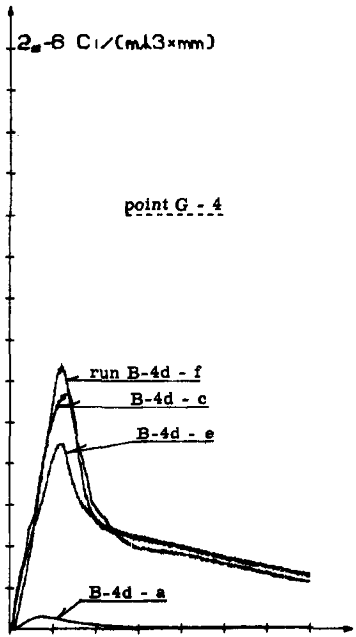


Fig. A IV - 3o.

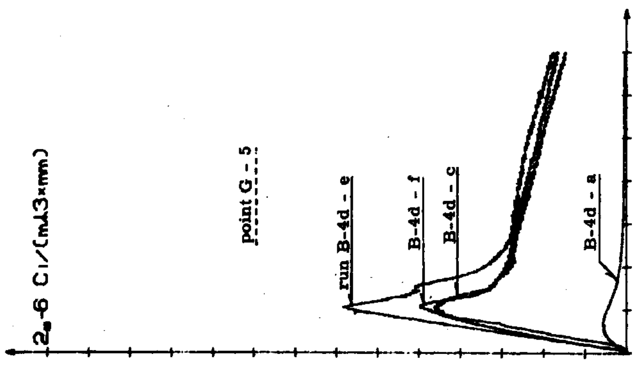


Fig. A IV - 31.

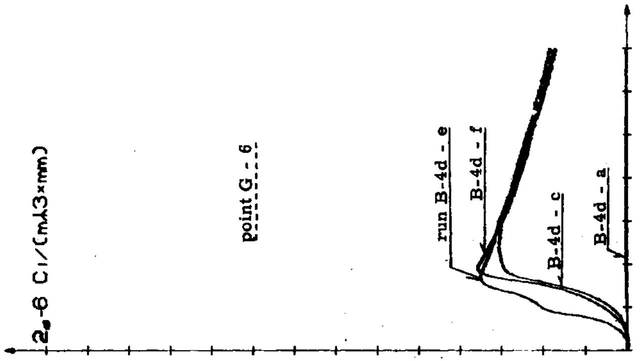


Fig. A IV - 32.

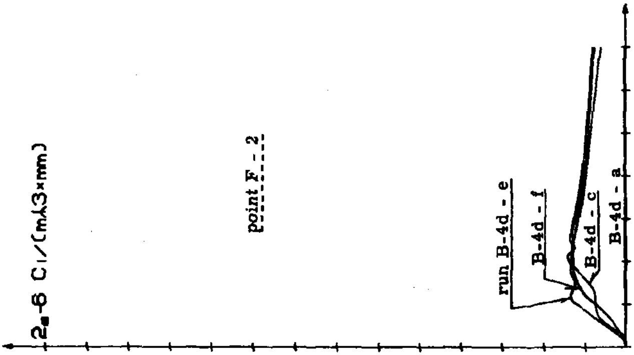


Fig. A IV - 34.

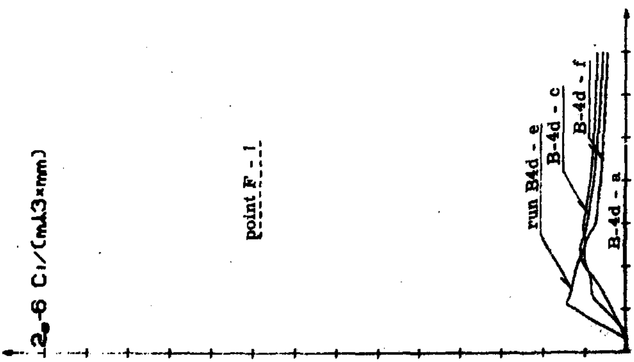


Fig. A IV - 33.

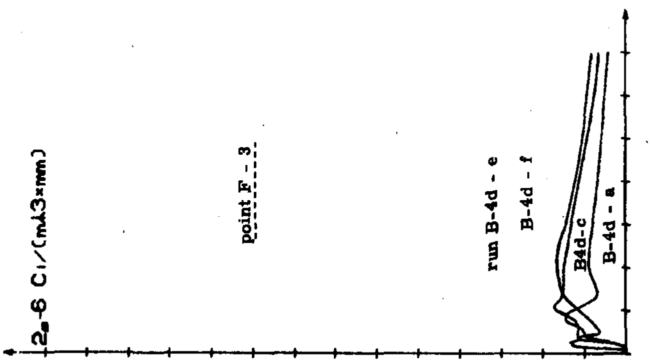


Fig. A IV - 35.

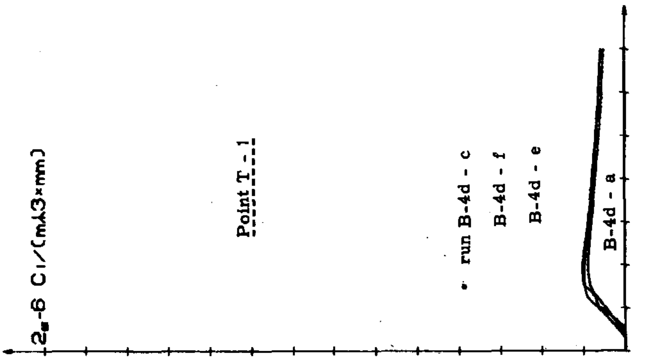


Fig. A IV - 36.

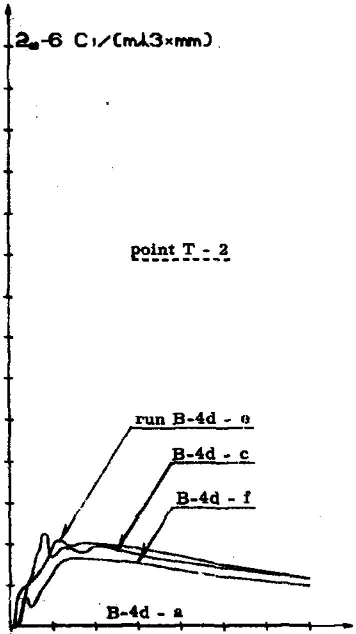


Fig. A IV - 37.

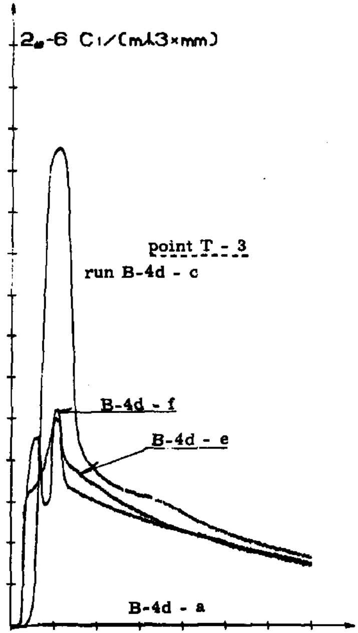


Fig. A IV - 38.

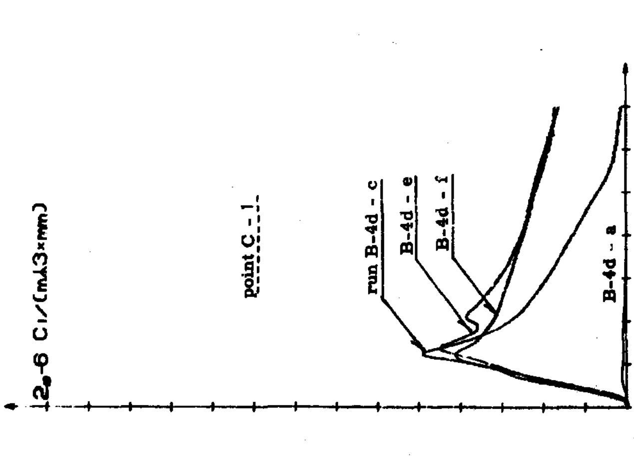


Fig. A IV - 39.

Appendix V

Figures A-V-1 to A-V-13. Activity release rate from stack (S-1), response of gamma-air-duct monitor (S-2) and activity concentration at the release point (S-3) vs. time after release of activity standardized to 1 C.
A-runs: release to top void,
B-runs: release to D_2O-room.

Run A-4a - BS established automatically by trip on gamma-air-duct monitors (100 mR/h). Active ventilation mainly from top void.

Run A4-c - as described in Appendix IV.

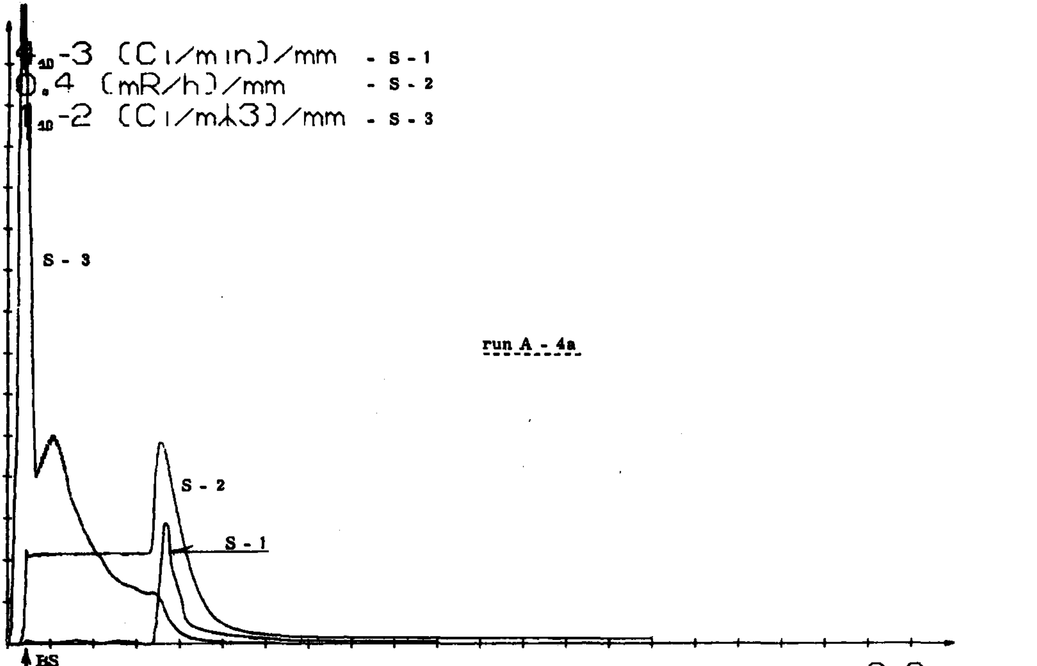

10-3 (Ci/min)/mm - S - 1
0.4 (mR/h)/mm - S - 2
10-2 (Ci/m3)/mm - S - 3
S - 3
S - 2
S - 1
run A - 4a
BS
0.2min/mm

Fig. A V - 1.

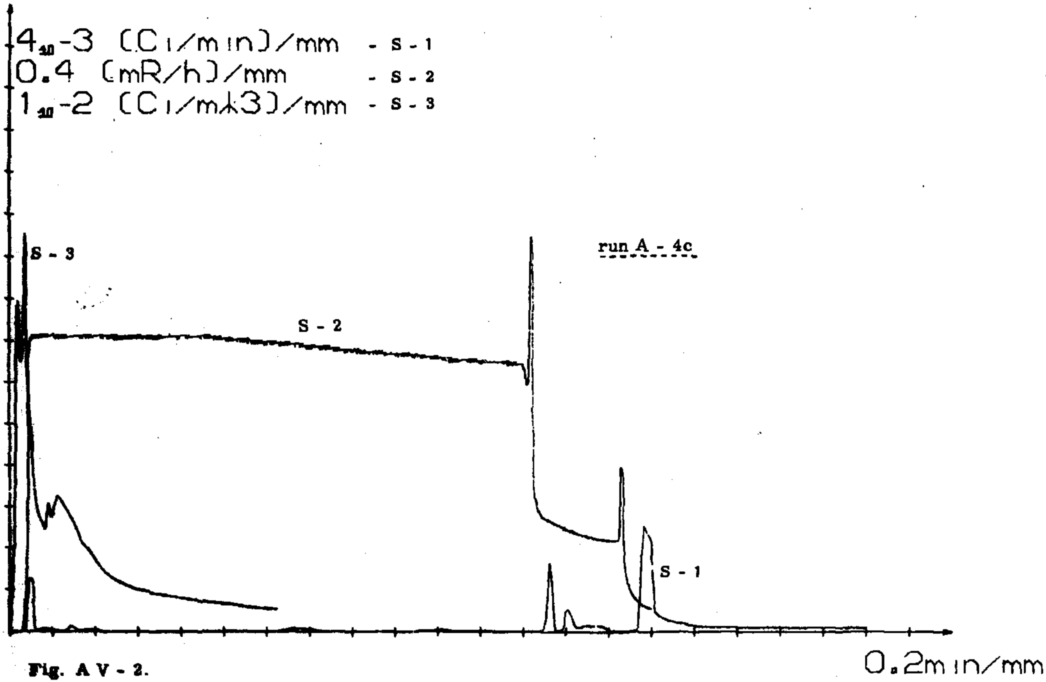
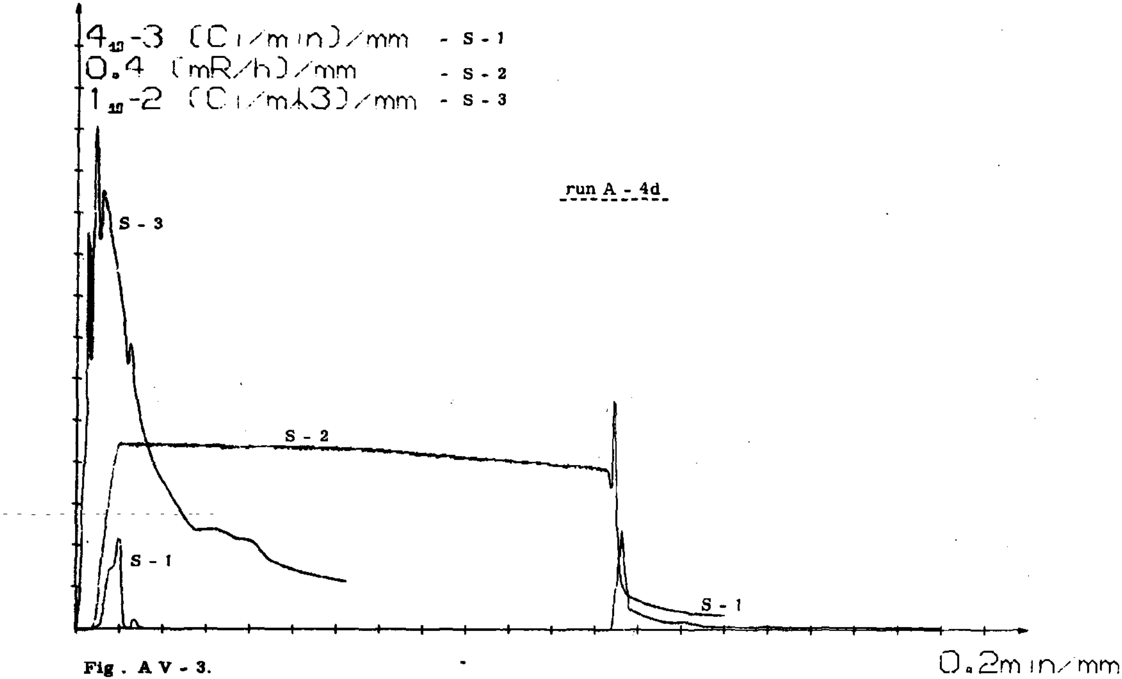
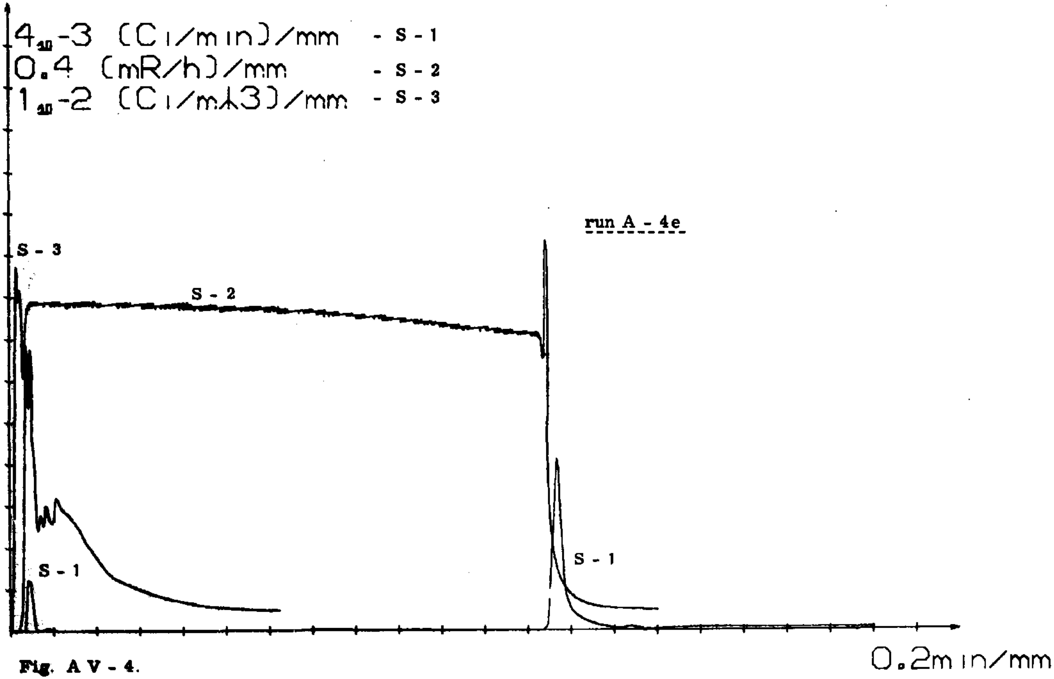

4 10-3 (Ci/min)/mm - S - 1
0.4 (mR/h)/mm - S - 2
1 10-2 (Ci/m^3)/mm - S - 3
S - 3
S - 2
run A - 4c
S - 1
0.2min/mm

Fig. A V - 2.



4 10-3 (Ci/min)/mm - S - 1
0.4 (mR/h)/mm - S - 2
1 10-2 (Ci/m^3)/mm - S - 3
run A - 4d
S - 3
S - 2
S - 1
S - 1
0.2min/mm

Fig . A V - 3.



4 10-3 (Ci/min)/mm - S - 1
0.4 (mR/h)/mm - S - 2
1 10-2 (Ci/m3)/mm - S - 3
run A - 4e
S - 3
S - 2
S - 1
S - 1
0.2min/mm

Fig. A V - 4.

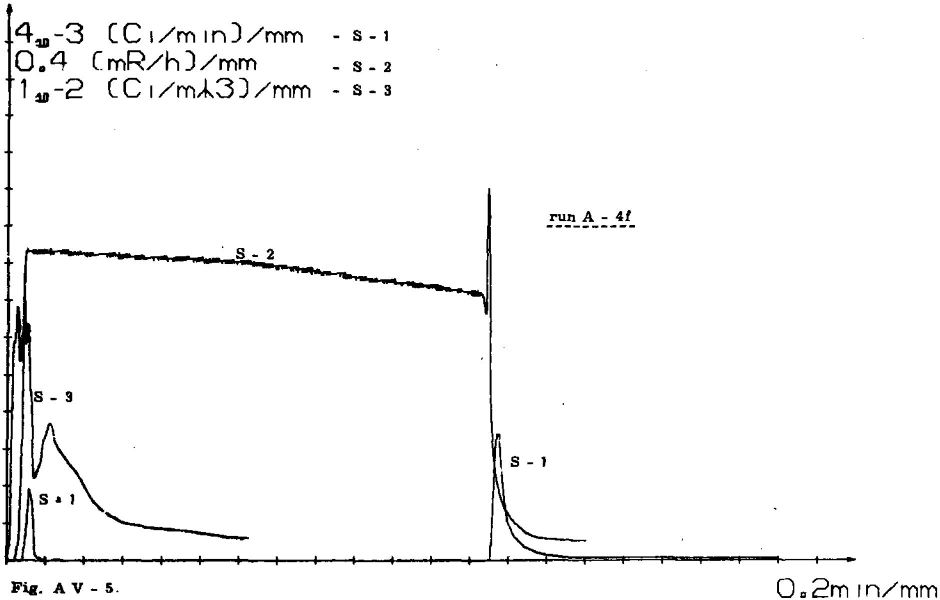

4 10-3 (Ci/min)/mm - S - 1
0.4 (mR/h)/mm - S - 2
1 10-2 (Ci/m3)/mm - S - 3
run A - 4f
S - 2
S - 3
S - 1
S - 1
0.2min/mm

Fig. A V - 5.

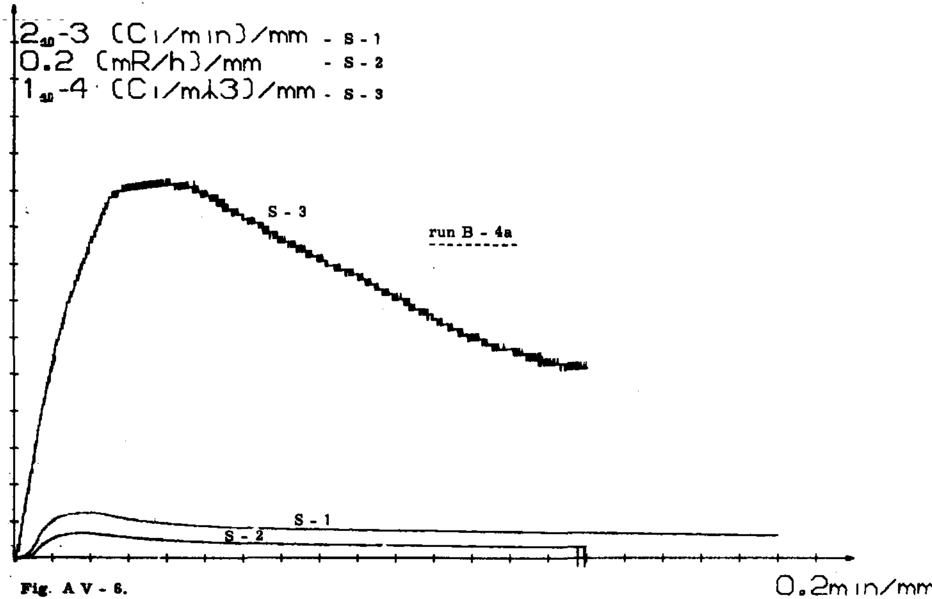

2x10-3 (Ci/min)/mm - s - 1
0.2 (mR/h)/mm - s - 2
1x10-4 (Ci/m3)/mm - s - 3
S - 3
run B - 4a
S - 1
S - 2
0.2min/mm

Fig. A V - 6.

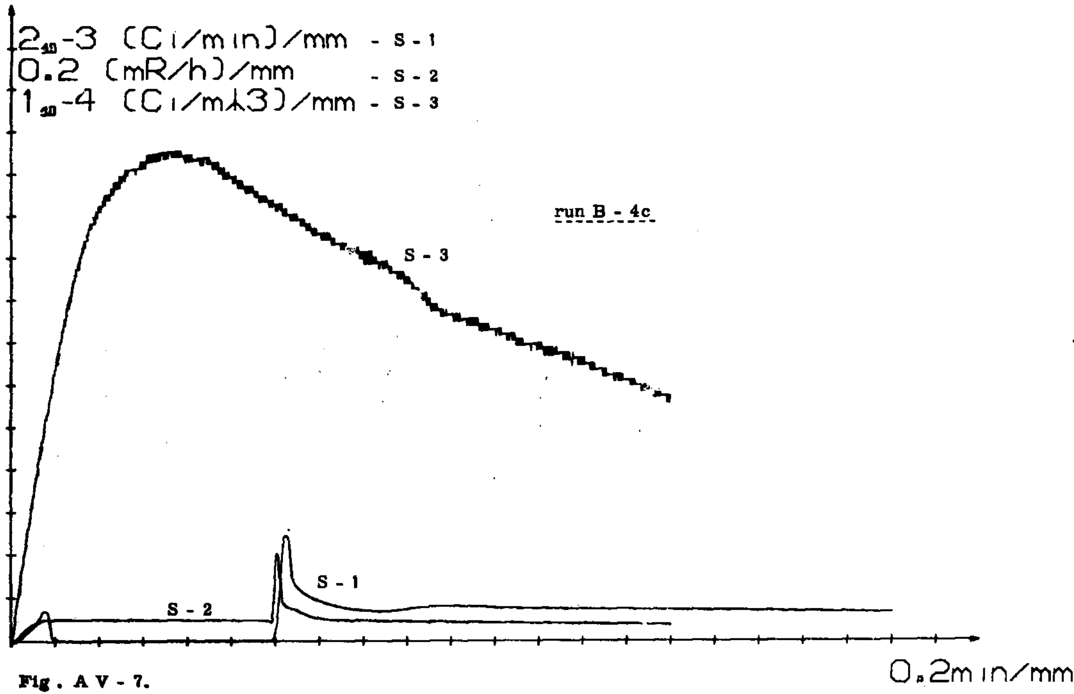

2E-3 (Ci/min)/mm - S - 1
0.2 (mR/h)/mm - S - 2
1E-4 (Ci/m^3)/mm - S - 3
run B - 4c
S - 3
S - 1
S - 2
0.2min/mm

Fig. A V - 7.

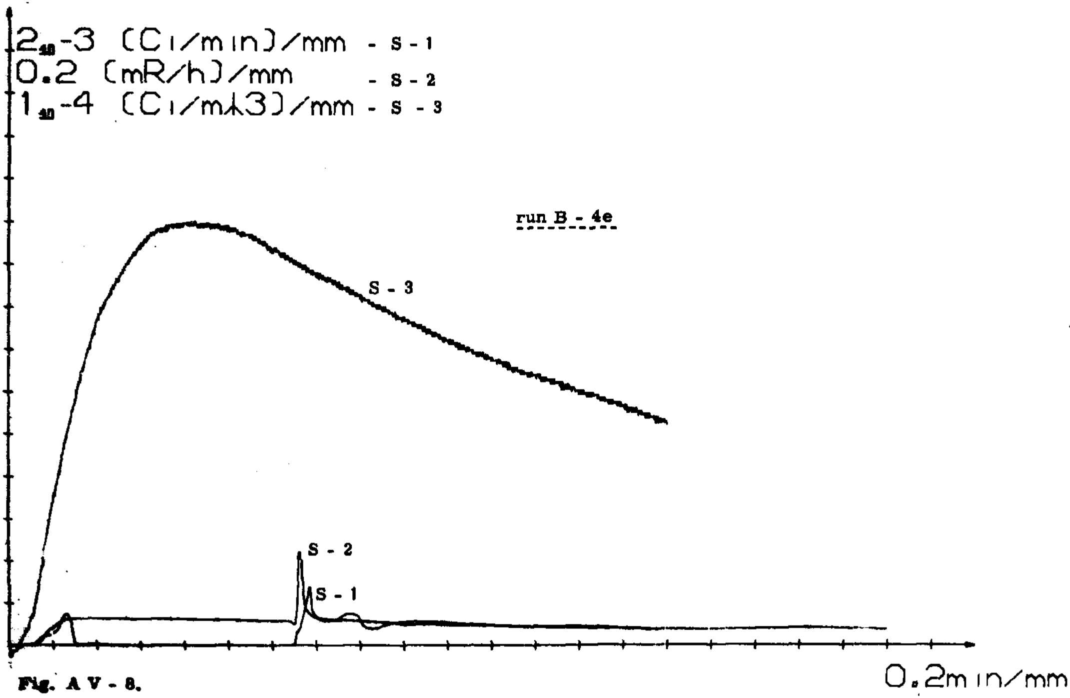
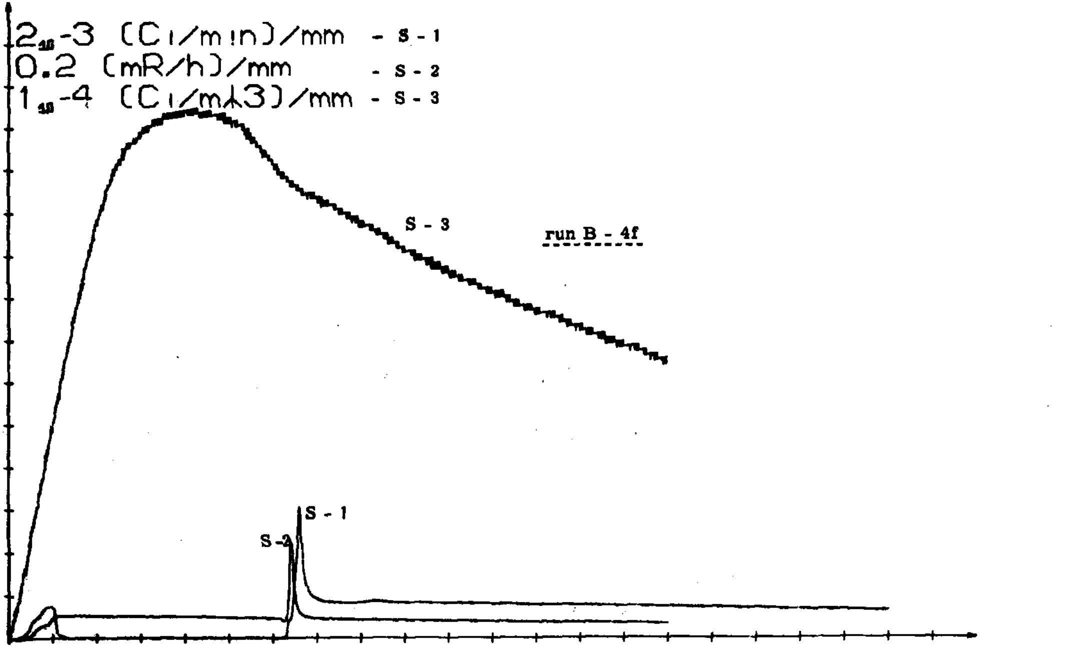

2E-3 (Ci/min)/mm - S - 1
0.2 (mR/h)/mm - S - 2
1E-4 (Ci/m^3)/mm - S - 3
run B - 4e
S - 3
S - 2
S - 1
0.2min/mm

Fig. A V - 8.



2E-3 (Ci/min)/mm - S - 1
0.2 (mR/h)/mm - S - 2
1E-4 (Ci/m^3)/mm - S - 3
S - 3
run B - 4f
S - 1
S - 2
0.2min/mm

Fig. A V - 9.

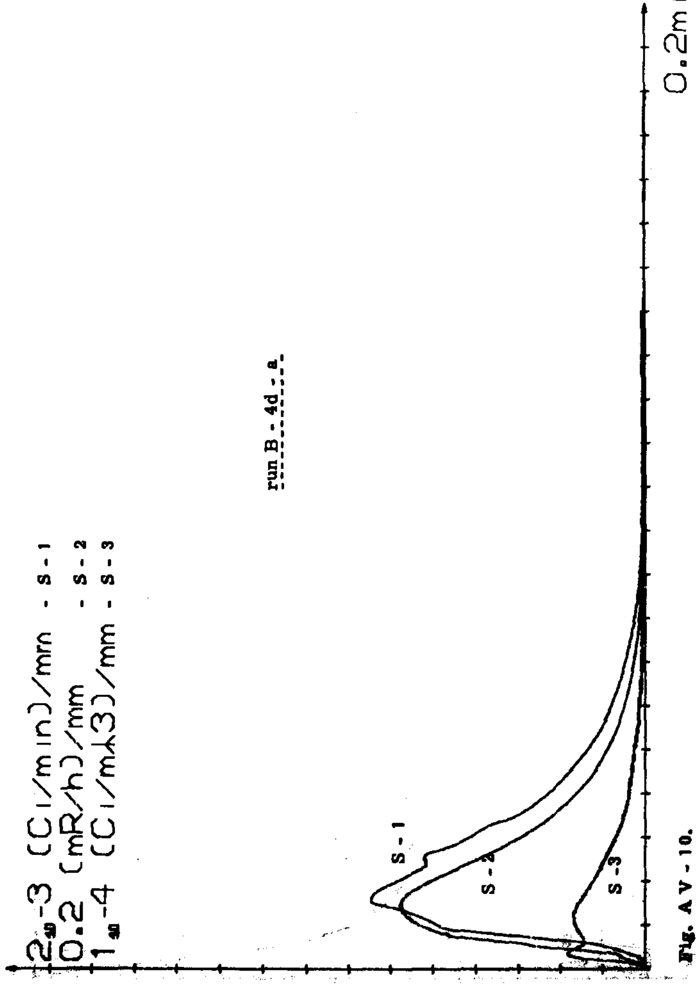

2 10 -3 (Ci/min)/mm - S-1
0.2 (mR/h)/mm - S-2
1 10 -4 (Ci/m3)/mm - S-3
0.2min/mm
run B - 4d - a
S-1
S-2
S-3

Fig. A V - 10.

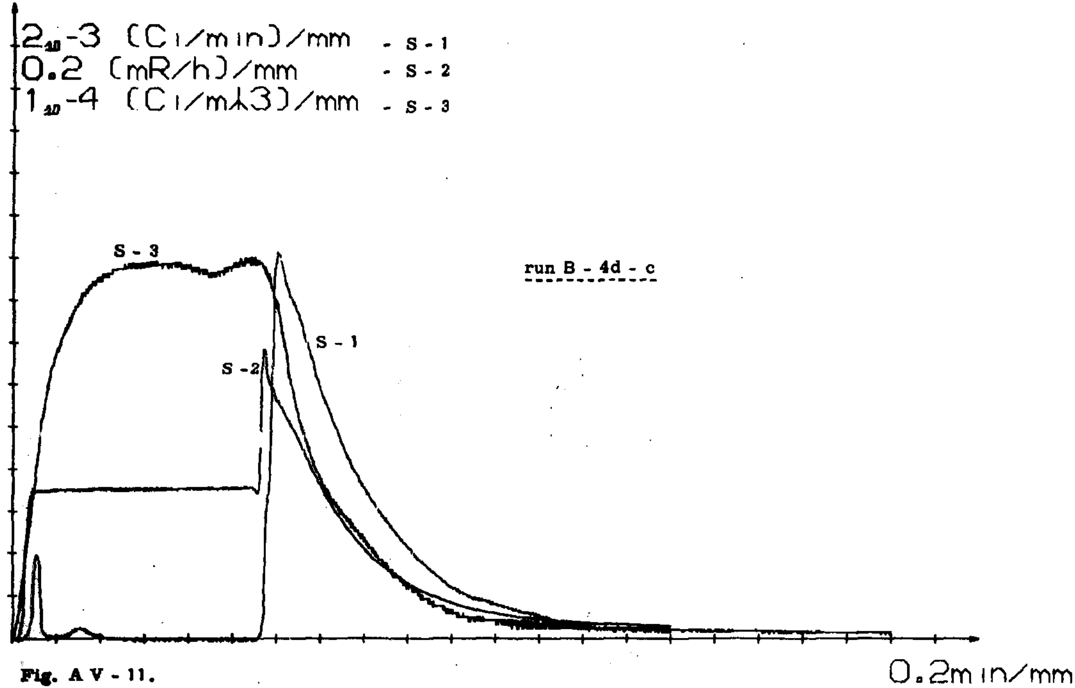

2 10-3 (Ci/min)/mm - S-1
0.2 (mR/h)/mm - S-2
1 10-4 (Ci/m^3)/mm - S-3
S - 3
run B - 4d - c
S - 1
S -2
0.2min/mm

Fig. A V - 11.

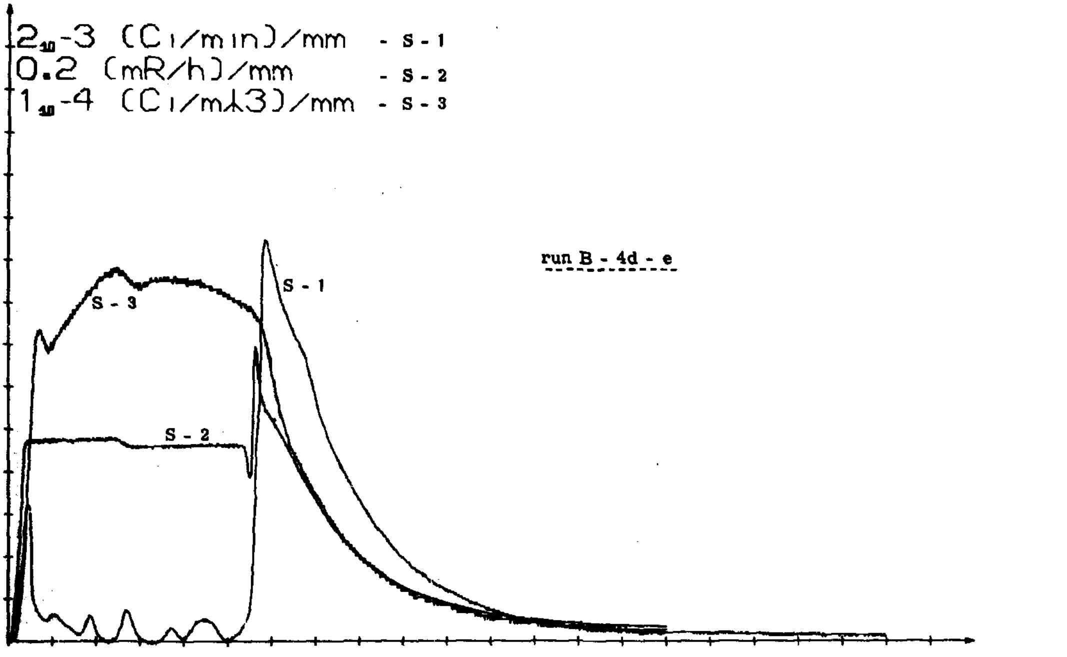

2 10-3 (Ci/min)/mm - S - 1
0.2 (mR/h)/mm - S - 2
1 10-4 (Ci/m^3)/mm - S - 3
S - 1
S - 2
S - 3
run B - 4d - e
0.2min/mm

Fig. A V - 12.

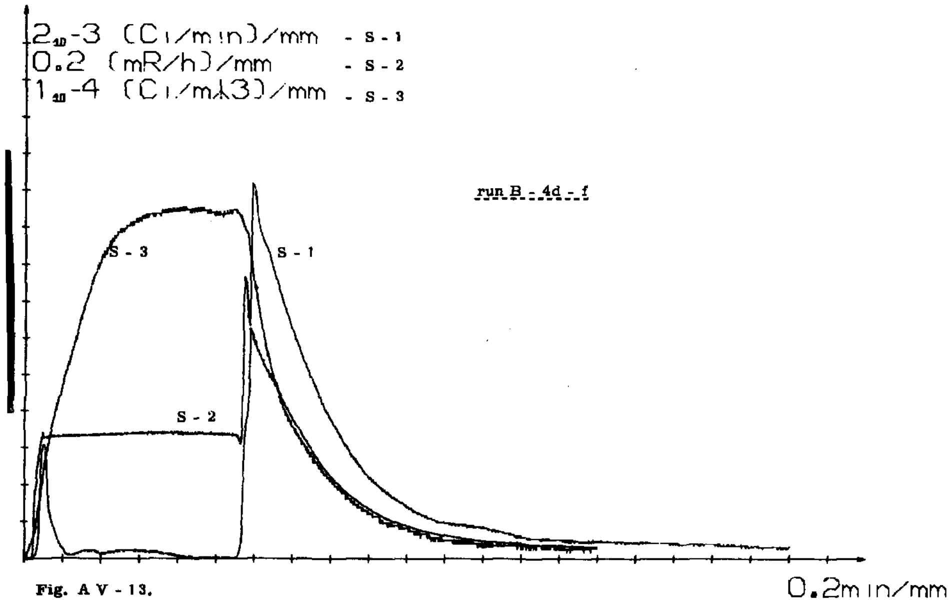

2 10-3 (Ci/min)/mm - S - 1
0.2 (mR/h)/mm - S - 2
1 10-4 (Ci/m3)/mm - S - 3
run B - 4d - f
S - 3
S - 1
S - 2
0.2min/mm

Fig. A V - 13.